OIL·SHALE·TRACT·C-b

ENVIRONMENTAL BASELINE PROGRAM

NOVEMBER '74-
OCTOBER '76
FINAL REPORT

HYDROLOGY

VOLUME 2

C-b SHALE OIL VENTURE • ASHLAND OIL, INC.
OCCIDENTAL OIL SHALE, INC., OPERATOR

U. S. DEPARTMENT OF THE INTERIOR

PROTOTYPE OIL SHALE LEASING PROGRAM

OIL SHALE TRACT C-b

ENVIRONMENTAL BASELINE PROGRAM

FINAL REPORT

(November 1974 Through October 1976)

VOLUME II

HYDROLOGY

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Results of the two-year Environmental Baseline investigation have delineated the major hydrological parameters for Tract C-b. These include stream flows, precipitation, water levels, and water quality. Some of the more significant findings are summarized briefly in this section.

Stream flows in Piceance Creek upstream and downstream from the Tract, and in the two perennial tributaries bordering the Tract exhibit large seasonal variations and are strongly affected by diversions for agricultural use. Flows in the normally dry tributaries which drain the Tract itself are very rare, and have been observed under natural conditions only following heavy rains.

Stream flow data gathered prior to the C-b lease suggest that a large instantaneous increase in base flow occurred in 1973 as a result of the Project Rio Blanco nuclear detonation a few miles from the Tract. Since that time, flow has gradually been returning to the pre-test conditions, so that the two years of Environmental Baseline data have been gathered on a declining curve.

Data obtained on flowrates of springs near the Tract have been inconclusive in establishing an annual cycle. Some springs do exhibit cyclic behavior. Data from other springs are incomplete because of agricultural diversions around the measuring flume in summer. An insufficient record is available for the pre-lease period to evaluate effects of the Project Rio Blanco detonation.

Water quality in Piceance Creek is a strong function of flowrate. Water quality is generally degraded with increasing distance downstream. Some changes due to specific inputs from tributaries have been identified, but the general increase in dissolved solids accumulates from non-point sources. Existing conditions in the area result in concentrations of several constituents which exceed proposed Colorado water quality standards. None of these excessive concentrations would pose a serious hazard to water users.

Samples from various springs were found to be quite similar in most respects. Highly saline springs, which are known to occur elsewhere in the basin, were not found. Concentrations of most constituents are in the same range as is found in the surface streams and the alluvial ground water. It was impossible to identify the source(s) of the springs by chemical analysis, but the lack of high fluoride levels would seem to indicate that these particular springs do not arise from the deep aquifers.

Water levels in the alluvium of Piceance Creek and its tributaries go through seasonal fluctuations as a result of spring snowmelt and summer rains. No significant direct pumping from the alluvium is known to occur. Some wells exhibit larger variations in water level than others, but the cause is not apparent.

Water samples obtained from alluvial wells exhibit the same general increase in dissolved solids content with downstream distance as is seen in the surface streams. However, there was no correlation between water quality and the seasonal cycles in water levels. This may be due to the way in which the alluvial wells were designed and the position in the aquifer from which samples were withdrawn.

Water level measurements in the deep aquifers confirmed the regional potentiometric contours previously established by USGS studies. No annual cycles were discerned. Some apparent anomalies in the data could not be completely resolved. One such indication is that of a "hill" or "mound" of water near the center of the Tract. This could be due to aquifer recharge by infiltration from the surface, or to increased vertical permeabilities along the lines of perennial stream flows, or to combined vertical and horizontal anistropy of permeability.

A second area of anomalous behavior is the generally increasing water level observed over the period of baseline observations. This could be a result of reaction to increases in precipitation and/or infiltration in the aquifer recharge areas, or of recovery from effects of the Rio Blanco detonation, or of changes caused by aquifer pumping tests and by open well bores in the Tract area. Calculations were made which showed that well bores in the Tract area which have been left open to both the upper and lower aquifers for a period of years could have a large effect on water levels in wells some distance away.

Water in the deep aquifers was found to be universally high in fluoride content. Just above and below the Mahogany zone, the total dissolved solids content is similar to that in the springs and surface stream. TDS increases with depth below the Mahogany zone and at greater depths there is an interval of extremely saline water. Some wells which penetrated this zone provided a path for migration of this saline water upward into the overlying aquifers. After this situation was detected, the wells were reworked to eliminate the interaquifer connections. Sampling from the wells after recompletion showed a gradual reduction of salinity in the affected aquifers.

In an attempt to define the sources of spring flows and the degree of interconnection between aquifers, a statistical comparison was made between water quality parameters for springs, the alluvial aquifers, the upper aquifer, and the lower aquifer. The results indicated, on a statistical basis, that each system comprised an independent population. It was not possible to define the source of spring flows from these data.

Aquifer pumping tests were conducted to determine basic hydrological parameters for the aquifers. Other data were then used to calculate the rate of water inflow to an underground mine and shafts. Several different organizations and types of computer simulation were used in this effort with widely varying results. The latest efforts have indicated that inflow to the mine will be considerably less than had been predicted by early studies of the problem. Reinjection of this water could minimize the effects on flow in nearby springs and streams.

1 INTRODUCTION

The Environmental Baseline Program for Hydrology included the measurement of flows in streams and springs and water levels in the various aquifers as well as the collection of water samples for analysis of constituents. A description of the parameters measured and the water sampling schedules may be found in Chapter 2. In Chapter 3, the Baseline programs are discussed individually. These include the surface water program, the ground water program, and correlation-modeling studies generated in the ground water program. Chapter 4 discusses utilization of the data gathered over the baseline period. This last chapter is intended to provide a basis for designing future monitoring and data gathering programs.

The C-b Oil Shale Tract is located in Rio Blanco County, Colorado, a little southeast of the center of the Piceance Creek basin (Figure 1-1). The Piceance Creek basin is the name given to a topographic basin area that is delimited by the outcrop of the Green River Formation. This area is part of the large structural basin also called the Piceance Creek Basin. To distinguish between these two areas, the structural basin will be referred to as the capital B-Basin and the topographic basin will be referred to as the lower case b-basin. This somewhat confusing terminology is compounded further by the fact that the Piceance Creek basin covers two separate river drainage systems -- the Piceance Creek system and the Yellow Creek system. Tract C-b is located on the Piceance Creek drainage system and is bordered on the north by the Piceance Creek valley.

While stream flow is continuous along the mainstem of Piceance Creek and the lower reaches of some of its major tributaries, it is ephemeral in the upper reaches of major drainages and all side-gullies and tributaries. Stream base flow, which amounts to more than one-half of the total flow, comes from the ground water rising to the surface at seeps and springs and through the alluvium. Peak flows occur during the early spring as rising temperatures cause the snow to melt. This snowmelt peak occurs from March to May. Isolated flow peaks occur throughout the summer months in response to convective thundershowers. Minimum flows are recorded during the growing season when diversions for irrigation deplete the flow.

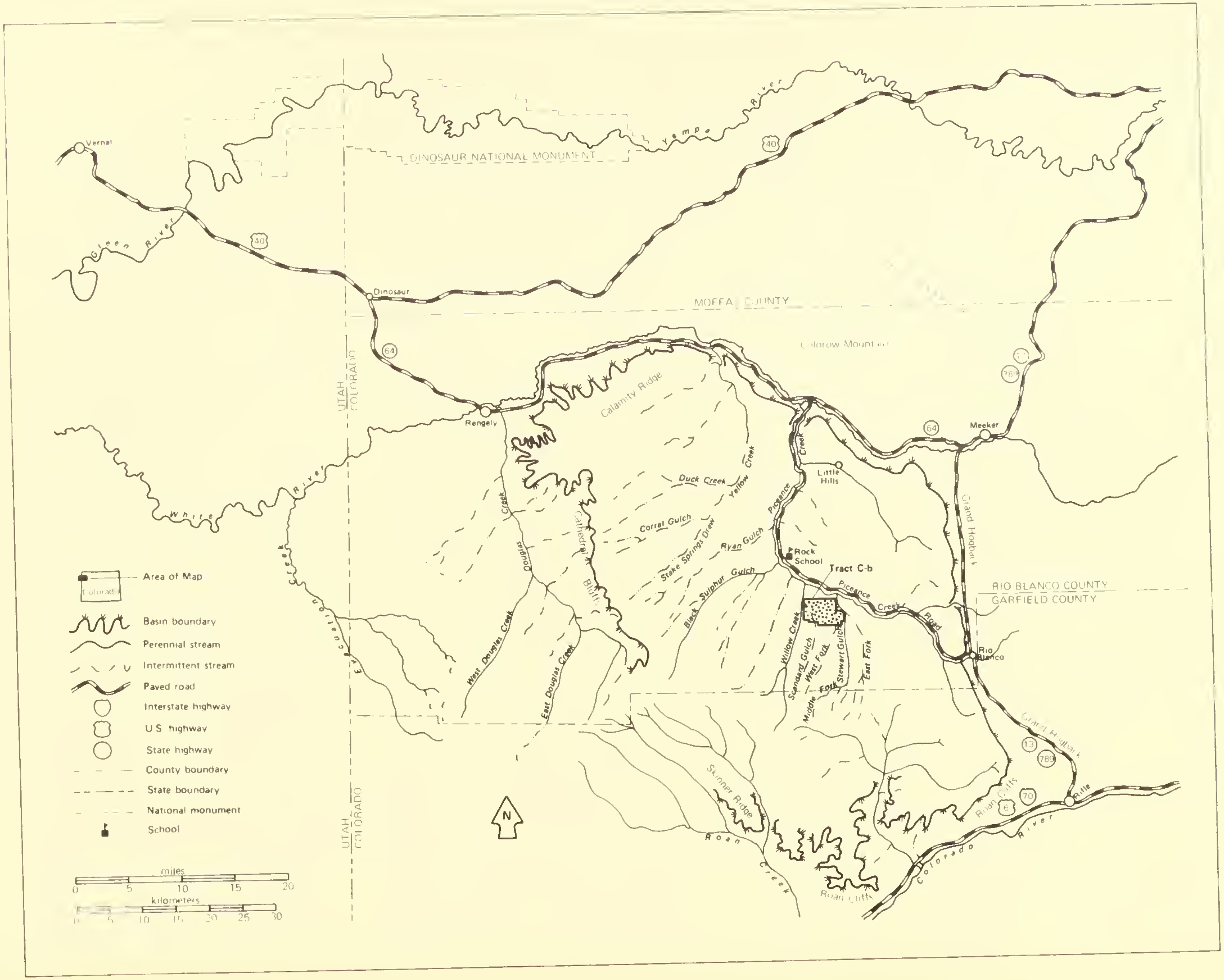


FIGURE 1-1

C-b OIL SHALE TRACT

In addition to the reduction in flow, irrigation affects water quality. Noticeable increases in total dissolved solids, sulfate, sodium, nitrates, and nitrites can be seen in the chemistry of Piceance Creek water below the Tract during the irrigation season. The waters of Piceance Creek are somewhat unusual in that two anions are nearly equally dominant, i.e., both bicarbonate and sulfate are present in quite high concentrations. Also, contrary to general experience with western surface waters, magnesium is the major cation rather than calcium. No reason for the anomalous dominance of magnesium is apparent. It could be attributed to leaching of magnesium from the marlstones found in the Uinta and Green River Formations. The increase in nitrates and nitrites during the irrigation season is attributed to livestock wastes and fertilizers in the irrigation return flow. A corresponding increase in dissolved solids, sulfates, and sodium is attributed to concentration by the reduction in flow, ionic exchange within the soils being irrigated, and an increased proportion of ground water in the surface flow.

The increase in the concentration of sulfate in the waters of Piceance Creek from 164 mg/l upstream of the Tract to 290 mg/l downstream of the Tract is attributed to the high sulfate waters contributed by two tributaries, Stewart Creek and Willow Creek. The same is true for other major ions such as calcium and magnesium.

A correspondence between the concentrations of major ions in seeps and springs and in the surface waters of Stewart Gulch and Willow Creek (Table 1-1) shows the reliance of these tributaries upon ground water contributions for their perennial flow. Except for bicarbonate, there is a good correspondence also with the mean concentrations of ions in the alluvial wells.

There is, however, no comparable correspondence between these water sources and the deep aquifer above the Mahogany mining zone, referred to as the upper aquifer.

Water samples were collected from the aquifers on a regular basis and from all water zones during the drilling of the core holes and test wells and during a series of aquifer tests. These aquifer tests consisted of two pump tests (one for the upper aquifer and one for the lower aquifer), a mini pump test, and a series of drillstem tests. The tests were designed to establish data on the physical characteristics of the aquifers and to investigate the presence of a series of aquitards. These data were necessary to formulate water management plans, to aid in mine design, and to test hypotheses concerning the effect on flow in aquifers and surface streams during mining operations.

Another characteristic important to the hydrology of an area is precipitation. Precipitation records from the microenvironmental

Table 1-1

CONCENTRATIONS OF SELECTED IONS
IN SURFACE AND GROUND WATERS OF TRACT C-b

	HCO_3	Ca	Cl	Mg	K	Na	SO_4
Piceance Creek							
Range	309-690	16-88	9-24	34-110	1-19	47-200	110-390
Mean	537	74	15	56	3.6	136	227
Tributaries							
Range	305-782	64-100	6-29	64-95	1-5	110-250	290-500
Mean	487	93	9	76	1.9	126	362
Seep & Springs							
Range	320-650	28-160	1-18	28-100	0.6-23	68-240	200-440
Mean	480	83	7	78	1.4	130	360
Alluvial Wells							
Range	320-730	16-102	1-29	20-120	0.7-5	93-730	200-530
Mean	540	67	11	80	1.5	175	370
Upper Aquifer							
Range	340-2100	3-120	2-510	2-150	0.3-11	44-1200	4-520
Mean	790	32	26	42	2.2	330	220

studies, from the air quality program, and from the surface hydrology program are incorporated within this volume. Precipitation is the driving force for the hydrologic system, whether it is expressed as runoff to surface water within a short time of the precipitation event, or whether it is finally expressed as base flow from ground water supplies months and years after the precipitation event. In this regard, it is interesting to study the surface water flow by seasons and by yearly average. Unfortunately, data are limited and the longest record on Piceance Creek includes only 11 years of observations. If a longer record were available, a relationship between precipitation and surface water flow could possibly be developed. As it is, with only two years of record on the Tract and only 11 years on Piceance Creek itself, such anomalies as the apparent doubling of flow after the nuclear blast of Project Rio Blanco May 17, 1973 cannot be fully interpreted.

A facet of precipitation behavior that has begun to be investigated only recently is the effect on water and soils brought about by chemical constituents in precipitation. Research seems to indicate that such effects are greater in the summer during violent updrafts and subsequent convective storms than in other seasons when frontal storms dominate. Enough data are available on the Tract to be able to see minor effects on stream chemistry due to precipitation. One event in particular is discussed when rain fell on frozen ground in February 1976.

2 PROGRAM DESCRIPTION

2.1 Lease Requirements and Stipulations

The Environmental Stipulations attached to the C-b lease establish a number of requirements for monitoring both surface and subsurface waters on and near the Tract. Objectives of these requirements are: (a) to establish baseline values for the quantity and quality of all water resources associated with the Tract, and (b) to provide a means for monitoring any future changes in these resources resulting from the development of an oil shale industry.

With respect to surface water it is specified that gauging stations are to be constructed on the major drainages of the leased lands and, as defined by the Area Oil Shale Supervisor, upstream and downstream from the leased lands. Data collected at these stations are to include continuous stream flow, water temperature, precipitation and sediment records, and periodic analyses for selected inorganic and organic chemical constituents.

An inventory of natural features, such as springs and seeps, is required.

Ground water requirements include:

(a) A test well at each proposed mine site.

(b) An observation well in each water-bearing zone defined by the test well.

(c) A pumping test in each water-bearing zone.

(d) Analysis of water from the pumping test for organic and inorganic chemical constituents.

(e) Records of water level and temperature in each observation well.

(f) After the initial test, collect water samples at six-month intervals.

(g) One observation well upgradient from any proposed spent shale disposal site and at least two observation wells downgradient.

2.2 Baseline Study

2.2.1 Objectives

The above general requirements, defined by the lease itself, have been translated into a number of detailed conditions of approval by mutual agreement between the Area Oil Shale Supervisor's office, the lessee, and various federal and state regulatory agencies.

In addition to satisfying the specific environmental monitoring requirements, the hydrology program has been designed to obtain information needed to estimate the problems of water inflow to an access shaft and mine, to evaluate the need for importation of surface water, and to investigate methods for disposing of excess water if necessary.

Aquifer characteristics such as transmissivity, storage coefficient, potentiometric surface, water quality, and discharge and recharge rates are sought to aid in the development of a mining plan and to predict local and regional effects which may develop because of ground water withdrawl.

2.2.2 Station Locations

Surface water gauging stations were constructed through a contract arrangement with the United States Geological Survey and the Colorado River Water Conservation District. The USGS Water Resources Division Sub-District office in Meeker, Colorado is responsible for operation and maintenance of the stations under this contract.

A total of 13 stations were installed on and near the Tract at the locations shown in Figure 2-1. The official USGS station numbers are shown. Nine of the stations are located on ephemeral or intermittent streams. The other four, however, are located on perennial drainages and are considered major gauging stations.

2.2.3 Well Locations

Four different classes of wells are utilized for hydrological observations:

(a) Shallow alluvial wells drilled specifically for the Baseline Environmental Monitoring Program.

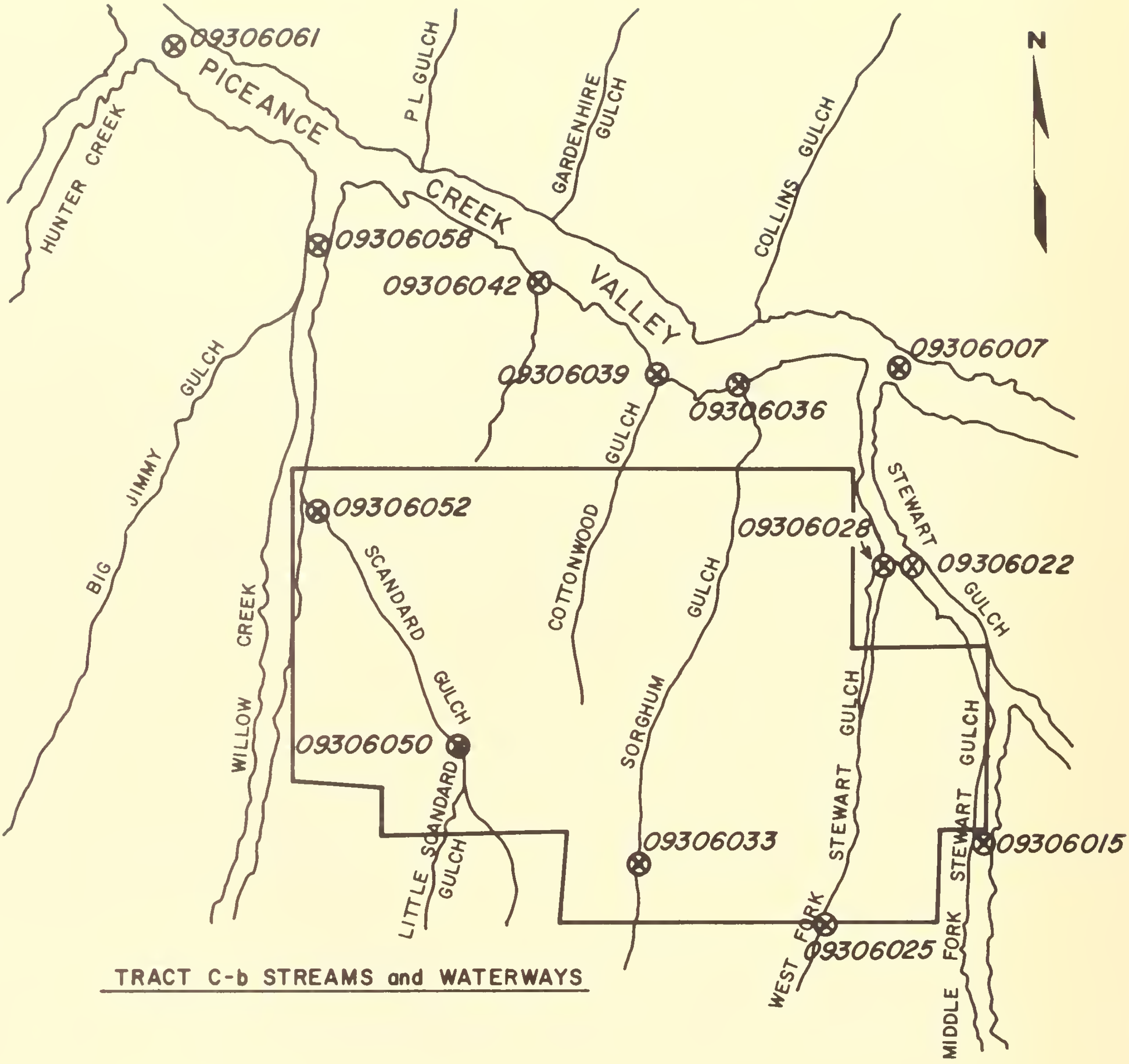


FIGURE 2-1

⊗ SURFACE WATER GAUGING STATION

(b) Deep wells drilled specifically for the required aquifer pumping tests.

(c) Deep core-holes completed as observation wells.

(d) Existing wells (core-holes) drilled by other parties previous to the C-b lease.

The locations of all wells are given in Figure 2-2. A total of thirteen alluvial wells were drilled, of which two were dry holes. Some of the close-in observation wells for the aquifer pumping test were used only for that purpose. Most other deep wells have been maintained as observation wells--a total of 18 wells containing a total of 27 tubing strings monitoring separate zones.

2.2.4 Parameters and Sampling Frequency

2.2.4.1 Surface Water

Table 2-1 lists the parameters measured continuously at the surface water stations. In addition to the continuous parameters, samples are collected periodically for chemical analysis. During the first year of the baseline program, samples were collected every two weeks from flowing stations. During the second year, the frequency was reduced to once a month and some changes made in the analytical schedule. Because the changes in constituents to be analyzed were minor, only the second year requirements will be listed:

(a) Owing to relatively low annual precipitation in the area and to freezing conditions during winter months, data collection related to stream flow at many of the gauging stations will often be on an opportunistic rather than a regular and routine basis. Four of the selected stations, however, are considered to be at locations where year-round flow can be expected. These four locations are:

(1) USGS No. 09306022 on Stewart Gulch above West Fork near Rio Blanco;

(2) USGS No. 09306058 on Willow Creek near Rio Blanco;

(3) USGS No. 09306061 on Piceance Creek above Hunter Creek near Rio Blanco; and

(4) USGS No. 09306007 on Piceance Creek below Rio Blanco.

The stations listed above are referred to as the "major" gauging stations. At the major stations, water sampling and analysis is done at specified frequencies.

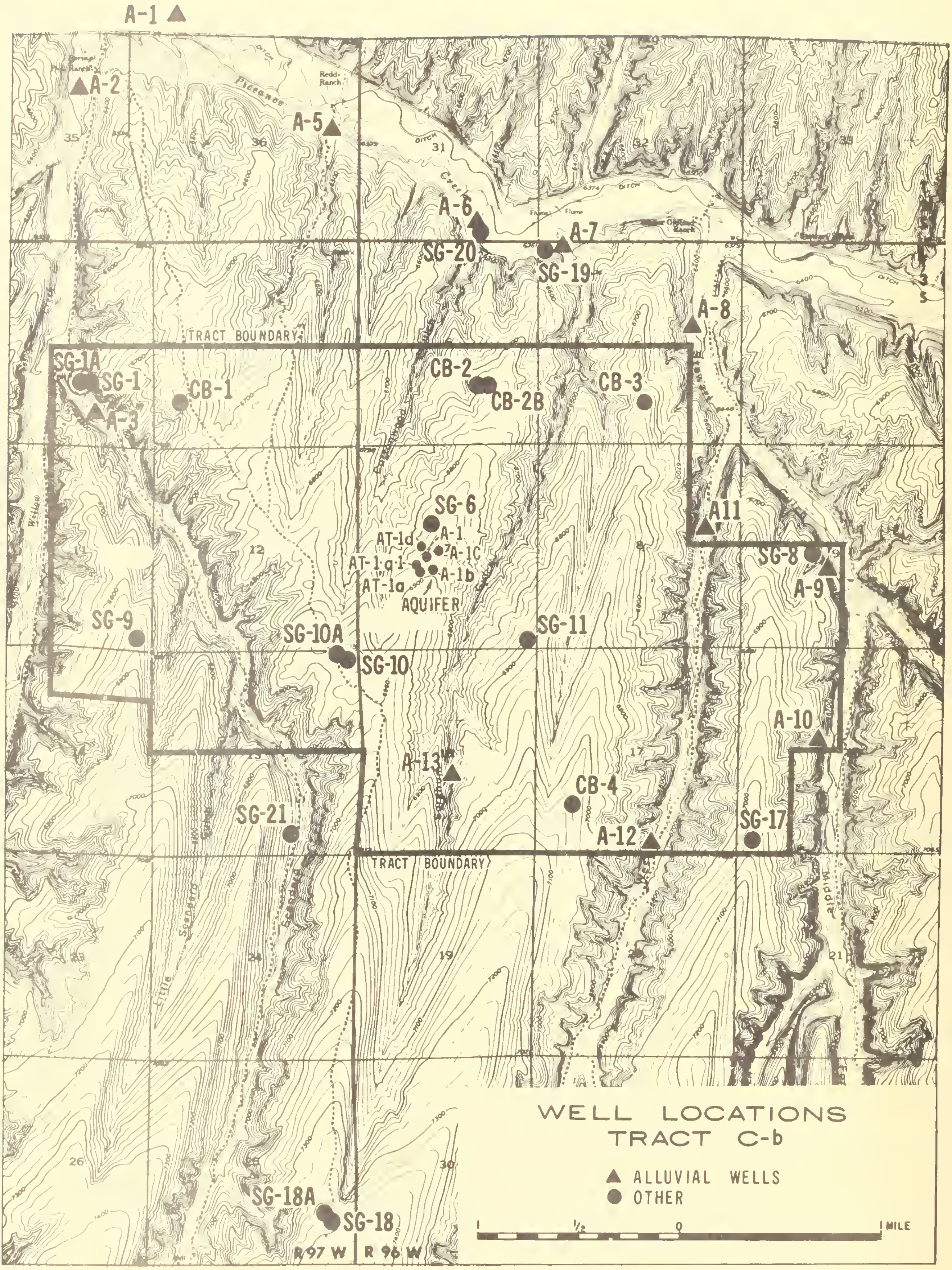

WELL LOCATIONS
TRACT C-b

FIGURE 2-2

Table 2-1 SURFACE WATER DATA--COLLECTION NETWORK

STATION	USGS No.	STREAMFLOW RECORDER	AUTOMATIC SUSPENDED SEDIMENT SAMPLER	TEMP. & SPEC. CONDUCTANCE RECORDER	STORAGE PRECIPITATION GAUGE	pH, DO, RECORDER	TURBIDITY RECORDER
1. Piceance Creek below Rio Blanco	09306007	X	X	X	-	X	X
2. Middle Stewart Gulch	09306015	X	X	X	X	-	-
3. Stewart Gulch above West Fork	09306022	X	X	X	X	X	-
4. West Fork Stewart Gulch, upstream	09306025	X	X	X	-	-	-
5. West Fork Stewart Gulch at mouth	09306028	X	X	X	-	-	-
6. Sorghum Gulch, upstream	09306033	X	X	X	-	-	-
7. Sorghum Gulch at mouth	09306036	X	X	X	-	-	-
8. Cottonwood Gulch	09306039	X	X	X	-	-	-
9. Trib. of Piceance Creek	09306042	X	X	X	-	-	-
10. Scandard Gulch, upstream	09306050	X	X	X	X	-	-
11. Scandard Gulch at mouth	09306052	X	X	X	-	-	-
12. Willow Creek	09306058	X	X	X	X	X	-
13. Piceance Creek above Hunter Creek	09306061	X	X	X	-	X	X

At all other stations, measurement, sampling and analysis is done during periods of stream flow, as close as possible to the required frequency. Great emphasis is placed on collecting data at all stations during unusual flow events, such as those following cloudbursts, large regional storms, or unusually high snow melt.

(b) Surface-water gauging stations, including continuous stage recorders, are maintained and operated and the listed parameters measured continuously, automatically, or as indicated as shown in Table 2-1.

(c) A site log is kept at each gauging station for sign-in and for compilation of a record of persons present, conditions noted, and of work performed at each visit.

(d) Field measurements are made monthly, in conjunction with the sampling described in paragraph (e) below, of water temperature, specific conductance, pH, DO, color, and odor.

(e) Water samples from each station are analyzed monthly, provided that flow occurs, for total alkalinity, ammonia, B, Ca, F, Fe, Mg, K, SiO_2, Na, HCO_3, CO_3, Cl, dissolved solids, Kjeldahl nitrogen (reported as N), nitrate plus nitrite (reported as N), As, Mn, phosphate (reported as total PO_4 and dissolved PO_4), dissolved organic carbon, suspended organic carbon, and SO_4.

(f) Water samples are analyzed quarterly (once every three months), provided that flow occurs, for Al, Br, Ba, Cd, Cu, Cr, oil and grease, Pb, Li, Hg, Mo, Se, sulfide, Zn, cyanide, Sr, fecal coliform, fecal streptococcus, total coliform, COD, BOD, and phenols. Analysis of appropriate elements are by atomic absorption or by comparable techniques.

(g) A complete element scan, using emission spectrographic techniques, is performed quarterly. Samples for the element scan are taken at the same time as are those in (f) above.

(h) Samples are taken at the two stations on Piceance Creek (09306007 and 09306061) and analyzed for MBAS. One such sampling is during the height of spring runoff, a second sampling during late summer low flow. The need for further samples is to be determined by the AOSS, pending initial results.

(i) Pesticides are determined on samples of sediment at the two Piceance Creek stations during late summer. The need for further sampling is to be determined by the AOSS, pending initial results.

(j) Water samples for organic analyses are collected twice yearly at the four major gauging stations, and on an opportunistic basis at the other stations. One sample is taken during the high flows accompanying the spring snow melt-runoff period, and one sample during the late summer low-flow period. The samples are analyzed for dissolved organic carbon, and the dissolved organic carbon is further analyzed for

(1) hydrophobic bases, acids, and neutrals, and for

(2) hydrophilic bases, acids, and neutrals.

(k) Radioactivity of samples of surface water is determined quarterly (every three months) at the four major gauging stations and at other stations quarterly, provided that flow occurs, or on an opportuntistic basis. If gross alpha activity is greater than four picocuries/liter, then the sample is analyzed for radium 226 and for natural uranium. If gross beta activity is greater than 100 picocuries/liter, the sample is analyzed for Sr90 and for Ce137.

(l) Storage type rain gauges are operated and data collected at the following gauging stations:

(1) USGS No. 09306022 Stewart Gulch above West Fork near Rio Blanco;

(2) USGS No. 09306015 Middle Fork Stewart Gulch near Rio Blanco;

(3) USGS No. 09306058 Willow Creek near Rio Blanco; and

(4) USGS No. 09306050 Scandard Gulch near Rio Blanco.

(m) Biotic surveys to determine numbers of individuals and species of periphyton and aquatic macroinvertebrates are coordinated with the water sampling program such that biotic data or changes thereof can be related to water quality.

(n) Characterization of sediment. Suspended sediment discharge is determined annually at all gauging stations. Samples of sediment are collected on major drainages affecting the Tract, with emphasis on possible disposal areas for processed shale. Such samples are analysed for their physical, chemical, and mineralogical properties. Analyses of the samples, which in the case of normally dry stream courses, could be samples of stream-bed material, include (1) microscopic study and description; (2) X-ray diffraction; (3) particle size analysis; (4) spectroscopic analysis; (5) additional trace element and carbon compound analyses as appropriate. The samples collected are of sufficient size to provide for present analyses and to provide for storage and preservation (air-dried) for future analytical study. The above sampling and analyses schedule is subject to revision by the AOSS, pending initial results.

(o) Water quality of precipitation. Data was collected in reconnaissance fashion, on the water quality of precipitation that falls on and about the Tract. Recognizing the limitations of time and the uncertainties related to both the meteorological unknowns in the area and to the research aspects of such data collection, the minimum program consists of data collection on or adjacent to the Tract at a station at the upwind side, and at one station on the downwind side of the Tract. "Upwind" and "downwind" refer to general wind directions during seasonal precipitation periods as judged from data collected thus far in the meteorological program. Additional stations, off-Tract, at distances of several miles from Tract may be included by lessee, or may be required at a later date by AOSS, pending initial results.

Providing that adequate and appropriate precipitation occurs, samples are taken (1) of existing snow pack during the late winter; (2) of precipitation from regional storms (rainfall) that typically occur during late spring and late fall, and (3) of summer thundershower-type precipitation. In addition to measuring the amount of precipitation represented in each sample, analyses of constituents and parameters is, insofar as practicable, as described for surface water stations, including those in the quarterly element scan, and those done by field methods at the sampling site.

2.2.4.2 Springs and Seeps

Table 2-2 lists those springs and seeps which have been sampled and the sampling frequency.

2.2.4.3 Alluvial Wells

The alluvial wells have been divided into two groups with different sampling frequencies as shown in Table 2-3. For the four key wells A-1, A-3, A-6, and A-7, sampling frequency has been increased to detect any possible short-term variations in water quality during the period when conditions in the alluvium would be expected to change most rapidly. These wells will be sampled during the months of February, April, May, June, July, August, September, and November. The other wells will be sampled in May and November.

2.2.4.4 Deep Wells

Deep wells are those that are completed in and open to aquifers older than the alluvium, typically the Uinta Formation and members of the Green River Formation. These wells have been divided into two equal groups, one of which is sampled annually, the other semi-annually. Table 2-4 lists these wells.

2.2.4.5 Ground Water Quality

The analytical schedules for ground water quality samples were also revised slightly for the second year. Six different analytical schedules (see Table 2-5) are involved. The complete 1976 ground water sampling program, giving numbers of samples and the analytical schedules to be used with each, is presented in Table 2-6.

Table 2-2

SPRINGS

Key Springs (Sampled Eight-Times Per Year)	Others (Sampled Two-Times Per Year)
1. S-3, Mouth of Stewart	1. S-1, Mouth of Stewart
2. S-9, Willow Creek	2. S-2, Stewart Gulch
	3. S-4, Stewart Gulch
	4. S-6, PL Ranch
	5. S-7, PL Ranch
	6. S-10, Willow Creek

Table 2-3

ALLUVIAL WELLS
(Figure 2-2)

Key Wells (Sampled Eight-Times Per Year)	Others (Sampled Two-Times Per Year)
1. A-1	1. A-2
2. A-3	2. A-5
3. A-6	3. A-8
4. A-7	4. A-9
	5. A-10
	6. A-11
	7. A-12

Table 2-4

DEEP WELL STRINGS
(Figure 2-2)

Key Strings (Sampled Semi-Annually)	Others (Sampled Annually)
1. SG-1, String 1	1. AT-1C, String 1
2. SG-1, String 2	2. AT-1C, String 2
*3. SG-6, String 1	3. Cb-1
*4. SG-6, String 2	4. Cb-2
*5. SG-6, String 3	5. Cb-4
*6. SG-8R	6. SG-10R
7. SG-9, String 1	7. SG-11, String 1
8. SG-9, String 2	8. SG-11, String 2
*9. SG-10A	9. SG-11, String 3R
10. SG-17, String 1	10. SG-18A
11. SG-17, String 2R	11. SG-19
*12. SG-20	12. SG-21

*To be sampled for organic analysis.

Table 2-5

GROUND WATER

ANALYTICAL SCHEDULE #1

(STANDARD)

1. Alkalinity
2. Ammonia
3. Arsenic
4. Boron
5. Bicarbonate
6. Calcium
7. Carbonate
8. Chloride
9. Fluoride
10. Iron
11. Magnesium
12. Manganese
13. Kjeldahl nitrogen (as N)
14. Nitrate + nitrite (as N)
15. Potassium
16. Silica
17. Sodium
18. Strontium
19. Sulfate
20. Color, odor
21. Oil and grease
22. Dissolved organic carbon
23. Total dissolved solids

ANALYTICAL SCHEDULE #2

1. Aluminum
2. Beryllium
3. Barium
4. Bismuth
5. Bromine
6. Cadmium
7. Chromium
8. Copper
9. Cyanide
10. Lead
11. Lithium
12. Gallium
13. Germanium
14. Molybdenum
15. Mercury
16. Nickel
17. Selenium
18. Sulfide
19. Titanium
20. Vanadium
21. Zinc
22. Zirconium
23. Phenols

ANALYTICAL SCHEDULE #3

1. Chemical Oxygen Demand

Table 2-5 Continued

ANALYTICAL SCHEDULE #4

1. Fractionation of organic carbon into
    a. Hydrophobic bases
    b. Hydrophobic acids
    c. Hydrophobic neutrals
    d. Hydrophilic bases
    e. Hydrophilic acids
    f. Hydrophilic neutrals

ANALYTICAL SCHEDULE #5

1. Gross alpha radioactivity. If greater than 4 pcl, then:
    a. Ra^{226}
    b. Natural uranium

2. Gross beta radioactivity. If greater than 100 pcl, then:
    a. Sr^{90}
    b. Ce^{137}

ANALYTICAL SCHEDULE #6

1. Fecal coliform

2. Total coliform

3. Methylene Blue Active Substances

4. Biological Oxygen Demand

Table 2-6

1976 GROUND WATER SAMPLING PROGRAM

	ANALYTICAL SCHEDULE #1	ANALYTICAL SCHEDULE #2	ANALYTICAL SCHEDULE #3	ANALYTICAL SCHEDULE #4	ANALYTICAL SCHEDULE #5	ANALYTICAL SCHEDULE #6
FEB	4 A-wells 2 springs 2 snow	4 A-wells 2 snow		2 snow	2 snow	
MAR						
APR	4 A-wells 2 springs					
MAY	12 D-wells 11 A-wells 8 springs 2 rain	12 D-wells 8 springs 2 rain	6 D-wells 2 springs 2 rain	4 A-wells 6 D-wells 4 streams 2 springs 2 rain	11 A-wells 6 D-wells 8 springs 2 rain	
JUN	4 A-wells 2 springs					
JULY	4 A-wells	4 A-wells	4 A-wells			4 A-wells
AUG	4 A-wells 2 springs 2 rain	2 rain				
SEP	4 A-wells 2 springs					
OCT						
NOV	26 D-wells 11 A-wells 8 springs	26 D-wells 11 A-wells 8 springs	26 D-wells	4 streams	26 D-wells 11 A-wells 8 springs	

(See Table 2-5 for parameters)

3.1 Surface Water

3.1.1 Stream Flow

3.1.1.1 Rationale for Measurement

The amount of surface water flow is an important figure for those concerned with water rights, the agriculturalist, the industrialist, and the municipality. Even though this quantitative information is important, there are many streams particularly in the less populated areas of the western United States for which this information is not available. Prior to May 1974, this was true for the upper reaches of Piceance Creek, the nearest stream gauging station to the C-b Oil Shale Tract being about 10 miles downstream on Piceance Creek below Ryan Gulch. At that time this station had been operated only since 1964, limiting surface flow information on Piceance Creek to only 10 years. This length of time is short for an investigator to make unqualified analyses.

Because stream flow records were limited on Piceance Creek, and because exploitation of oil shale could affect stream flow through development activities, the Oil Shale lease required the operator of the C-b Shale Oil Project to establish baseline conditions of stream flow and water chemistry.

3.1.1.2 Objectives

The principal objective was to establish an environmental baseline for surface water quantity. Two years of data would provide a preliminary basis for estimating the variability of flow so that changes could be recognized and assessed. A secondary objective was to determine the amount of water resource which might be available for shale oil development.

3.1.1.3 Experimental Design

Terms of the Environmental Stipulations attached to the C-b Lease require that surface water gauging stations be located on the major drainages of the Tract and, as defined by the Area Oil Shale Supervisor, upstream and downstream of the leased lands. At these stations records are kept of stream flow, conductance, water temperature, sediment, and, at some stations, precipitation. Periodic analyses are made for selected chemical constituents.

Figure 2-1 (in the previous chapter) shows the approximate locations and official USGS number designation of the 13 stream gauging stations which have been installed on or near the Tract. Table 2-1 summarizes the instrumentation and data obtained at each location. The first data collection for the surface water program began on April 19, 1974.

3.1.1.4 Methodology

Stage is the elevation of a water surface in a stream at a specified station above some arbitrary zero datum. The zero datum is often set slightly below the point of zero flow in the stream. This zero datum is important because it is difficult to make direct and continuous measurement of the rate of flow in a stream but relatively simple to obtain a continuous record of water surface elevation. The primary field data gathered at a streamflow measurement station are related to stage. These stage data are then transformed to flow data for reporting purposes. Transformation is accomplished through the use of stage-discharge relationships empirically derived from a series of periodic flow measurements.

Continuous water-stage recorders use the motion of a float to record changes in elevation, i.e., stage. The motion of the float moves a pin across a long strip chart; clocks can be weight driven or battery operated. The float-type water-stage recorder requires a stilling well which serves to protect the float and counterweight cables from floating debris and supress fluctuations resulting from surface waves in the stream.

All recorders installed by the USGS on or near the Tract are Leopold Stevens A35 with analog strip charts. They are weight-driven. All have bank installations, that is, the stilling well is located on the bank and is connected to the stream by two-inch intake pipes.

3.1.1.5 Results and Discussion

3.1.1.5.1 Parameters and Variations

Although the continuous recording stations provide data on flow, sediment concentrations, turbidity, conductivity, temperature, dissolved oxygen, and pH, it is only the flow with which this section is concerned. The other parameters are discussed in the section on surface water quality.

Flow is usually reported in cubic feet per second (cfs) or in acre-feet. Metric equivalents are cubic meters per second (m^3/s) or liters per second (l/s) and cubic hectometre (hm^3). Conversion factors from English units to metric units are given in the following table.

Table 3-1 FACTORS FOR CONVERTING ENGLISH UNITS TO METRIC UNITS

MULTIPLY ENGLISH UNITS	BY	TO OBTAIN METRIC UNITS
cubic foot (ft^3)	.02832	cubic meter (hm^3)
cubic foot per second-day (ft^3/s-d)	.002447	cubic hectometer (hm^3)
Acre-foot (acre-ft)	.001233	cubic hectometer (hm^3)
cubic feet per second (cfs)	28.32	liter per second (l/s)
	.02832	cubic meter per second (m^3/s)

Discharge is commonly reported in cubic feet per second, mean value per day. The average flow in cubic feet per second for any 24-hour period is the volume of flow in second-foot-days (sfd). One sfd equals 86,400 cubic feet. Another common unit of volume is the acre-foot, the volume of water required to cover an acre to a depth of one foot. An acre-foot contains 43,560 cubic feet and equals 0.504 sfd. (Within an error of one percent, one acre-foot equals one-half sfd.)

Stream flow data, as a mean data flow, is the average discharge rate in cfs for the period from midnight to midnight. Maximum instantaneous flow on large streams may be only slightly higher than maximum mean daily flow. On small streams, the maximum instantaneous flow is usually much greater than the highest mean daily flow. See, for example, Table 3-2.

The stream flow data actually published by the USGS are carefully reviewed and adjusted for errors resulting from instrumental and observational deficiencies and commonly are adjusted for diversions made above the gauge. This is done prior to publication and distribution to the public. Data presented herein are not adjusted and are classified as "Preliminary Data Subject to Revision." Therefore, any conclusions drawn from these data are subject to revision.

Table 3-2 .RELATION BETWEEN MAXIMUM INSTANTANEOUS FLOW AND MEAN DAILY FLOW FOR SELECTED STATIONS

USGS Station	Basin Size (sq. mi.)	1975 Max. Instantaneous Flow (cfs) and Date		Mean Daily Flow Same Day (cfs)	Mean Daily Flow Max. for Year (cfs)	
Willow Creek nr. Rio Blanco 09306058	48.7	14	on June 28	2.9	5.8	on August 3 & 4
Piceance Creek above Hunter Crk. 09306061	309	95	on May 18	66	73	on May 19
Piceance Creek below Rio Blanco 09306007	177	104	on May 19	102	102	on May 19

3.1.1.5.2 Discussion

The surface water gauging stations established for this program are located on perennial and ephemeral water courses on or adjacent to the Tract. (Figure 2-1). Obviously, data on ephemeral streams are discontinuous and limited. Figure 3-1 presents the days on which stream flow was recorded at the nine minor gauging stations located on ephemeral stream courses. At these stations there is fairly good agreement between times of flow for the two water years of baseline.

Stream flow from the Piceance Creek drainage basin is typical of regions where the primary source of flow is snowmelt. Precipitation for the months of November through March is stored in the snowpack at higher altitudes of the basin and becomes available for runoff and ground water recharge as solar radiation and daily temperatures increase in the spring. Snowmelt produces a period of high stream flow starting in March or April and continuing through late May or June. Stream flow for the remainder of the year is maintained almost totally by ground water discharge, which moves through the alluvium into the stream channels or appears as springs along the valley floors. Evapotranspiration rates are high during the summer and most of the precipitation that occurs during this period is evapotranspired. Only high-intensity thunderstorms, which are usually limited to a small area, produce any significant contributions to summer stream flow.

Flow events occurred for the minor drainages on the Tract in February, March, the first of April, and during the summer. February, March, and early April would correspond to the local snowmelt season. The flow events recorded in June through September probably correspond to local convectional storm activity.

On the larger drainages base flow is attributed to seeps and springs. For example, flow on the West Fork of Stewart Gulch, where stream flow is continuous or almost continuous from May through November, is attributed to discharge to the stream from seeps and springs. In such drainages the thickness and character of alluvium in the valley floor plays a large part in whether stream flow is observed or not. Where the floor of the drainage way is mantled by alluvium, precipitation that would normally cause recordable stream flow infiltrates the surficial material. Until the alluvium is saturated no water will flow in the channel unless the rate of runoff is greater than the infiltration capacity of the alluvium. Another inhibitor to flow in a surface channel is vegetation. Near some springs and along Stewart Gulch in particular dense mats of rooted aquatic plants (Rorippa n. and Veronica sp) have inhibited flow and "....threaten to choke the creek." (Colo. Dept. of Health 1974).

DATES OF RECORDABLE STREAM FLOW ON MINOR DRAINAGES
1975-1976 WATER YEAR
TRACT C-b, PICEANCE CREEK BASIN, COLORADO

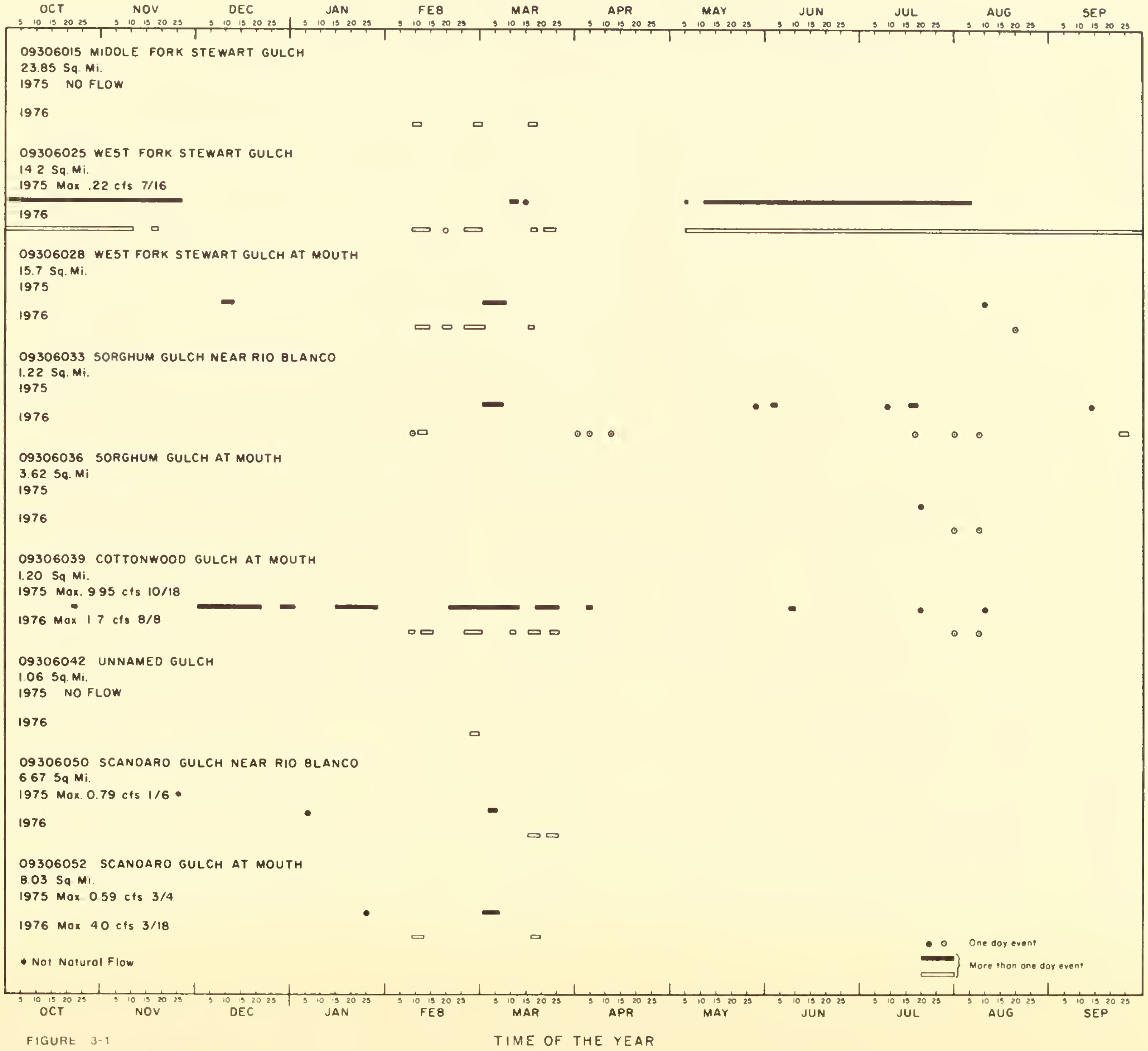


FIGURE 3-1

Flow periods of short duration in February and March could be attributed to rainfall on accumulated snow pack and the resultant runoff flowing over frozen or semi-frozen ground. Such a condition was observed on February 10 and 12, 1976, when a stream flow event was recorded following a frontal rainstorm.

Rain will melt the accumulated snowpack, thus adding the melt-water to the volume of rain. Raindrop temperatures approximate the surface wet-bulb temperature. As a raindrop enters snowpack, its temperature is reduced to $32^{\circ}F$ and the heat equivalent from the reduction in temperature is imparted to the snow. The melt from rain is given by

$$M = \frac{P(T-32)}{144}$$

where M is the inches of snowmelt, P is amount of rainfall, T is the wet-bulb temperature and 144 is the latent heat of fusion in BTU per pound (Linsley, et al. 1958).

Figure 3-1 shows the recordable stream flows at minor gauging stations; Figure 3-2 shows the precipitation events recorded on Tract C-b. Figure 3-18 in the following section, shows locations of precipitation stations. During the 1975 water year it appears that the flow events in February, March, April, July, August, and September, at all but the West Fork of Stewart Gulch and Cottonwood Gulch, were the result of wide-spread precipitation events. Similarly, in 1976, the majority of stream flow events in February, March, July, and August reflect precipitation events. The July and August 1976 stream flow events correlate with recorded precipitation in the C-b Tract area. However, recordable precipitation in the first week of March and on the 14th of June 1976 as well as several small rain showers in April and May 1975 are not reflected in the stream flow records.

The May through November flow on the West Fork of Stewart Gulch must reflect base flow from seeps which are frozen during the winter. No springs or seeps are reported in Cottonwood Gulch. The 1975 flow recorded in December, January, February, and March reflect the discharge from the upper aquifer pump test in December 1974 to mid-January 1975, and the lower aquifer pump test in February and March 1975.

The upper aquifer pumping test began at Well AT-1 November 30, 1974, with 400 gallons per minute discharge. Pumping continued until December 23, 1974, at an average rate of 356 gallons per minute. From December 28th to January 2nd a pulse test was conducted. (A pulse test is where the pump is alternately on and off for specified time periods.) Well AT-1 is about two miles from the gauge on Cottonwood Gulch. The approximate 1 cfs discharge at the well accounted for a recorded flow of .38 cfs at the gauge. The difference is accounted

DATES OF RECORDABLE PRECIPITATION*
TRACT C-b OVER BASELINE

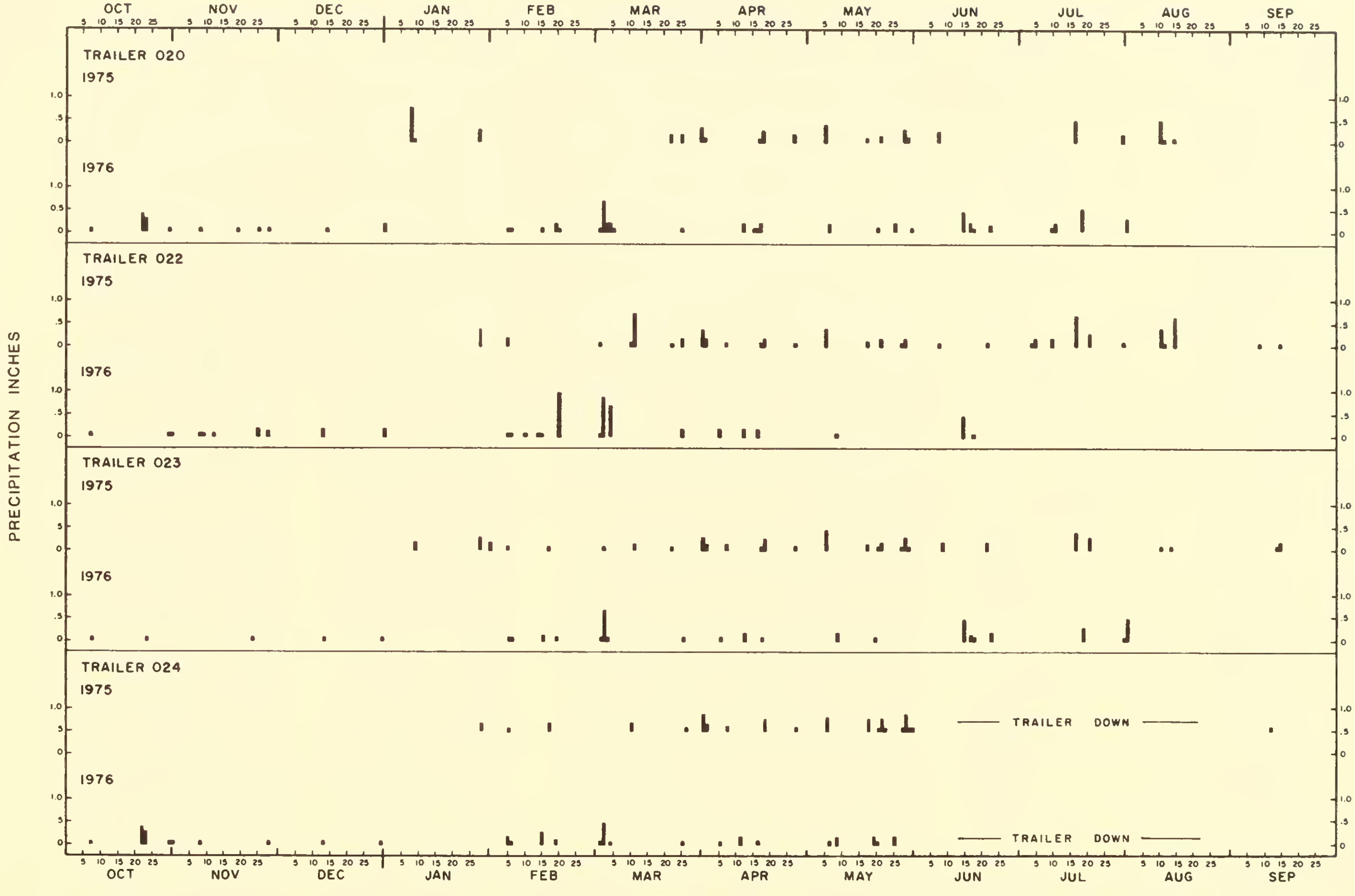


FIGURE 3-2

*AIR QUALITY STATION

for as being lost in the soil mantle below the well into the alluvium and a minor amount to evaporation.

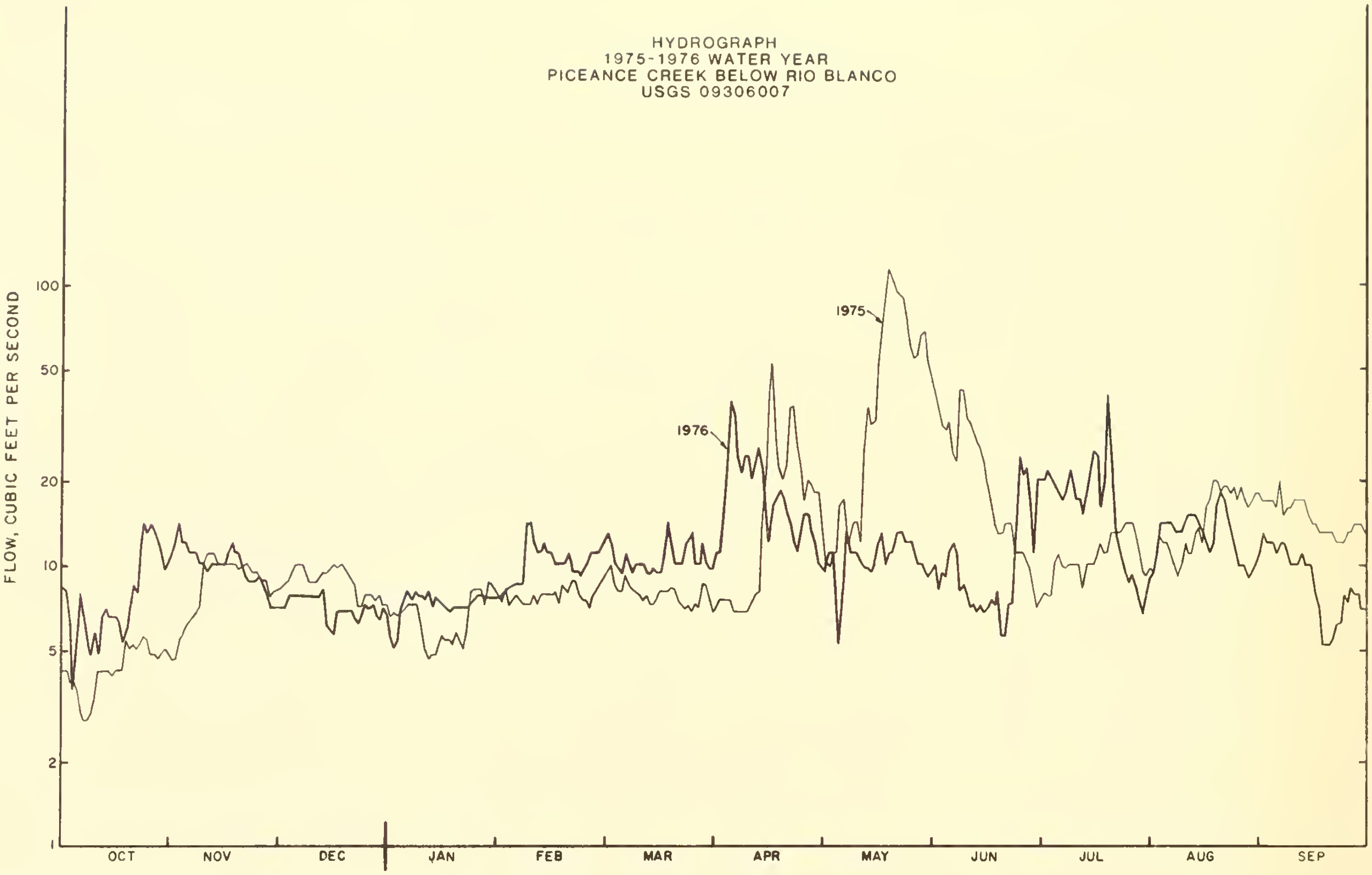
The lower aquifer test began February 5, 1975, with a six-hour surge test. On February 15, 1975, discharge commenced at 150 gallons per minute. Equipment failure on February 16th interrupted initial testing until February 21st when pumping began at 120 gallons per minute and continued until March 10, 1975. Pulse test drawdown was carried on between March 18th and March 26th. Stream flow records at Cottonwood Gulch reflect these activities (Figure 3-1).

On Piceance Creek, the early peak of stream flow (Figure 3-3) can be explained by snowmelt and spring precipitation events. For example, measurements of snowpack for 1975 water year indicate an average melt of 24 inches in March for Altenbern, Little Hills, and Meeker. There was an abrupt increase in stream flow at Piceance Creek above Hunter Creek during the last week of February which continued through March (Figure 3-3). Peaks in April can be reasonably correlated with widespread precipitation events, i.e., frontal rains recorded at many stations in the Piceance Creek areas as well as at the stations on the Tract.

During the 1975-1976 winter season the average total snowfall at Meeker, Altenbern, and Little Hills was 82 inches. In 1976, the change in snowpack from February to March averaged 21 inches and in April averaged 14 inches. Peaks above baseflow on the stream hydrograph reflect these assumed snowmelt events (Figures 3-3 and 3-4). Peaks throughout the summer appear to correlate with summer storms, however, major reduction in stream flow occurred from April to September, particularly when comparing flow between stations above the Tract at 09306007 and below the Tract at 09306061. This change in flow is the result of irrigation diversions. These diversion structures and the 1975 quantity of diversion are listed in Table 3-3. These diversion figures are unofficial and 1976 unofficial diversion quantities will not be available until mid-year 1977.

Diversions downstream from the USGS Station on Piceance Creek above Hunter Creek (09306061), have not been listed or tabulated. Reported yearly flows by USGS (not adjusted) from Piceance Creek stations are shown on Table 3-4.

Concerning the surface flow in Piceance Creek, the increase at Piceance Creek above Ryan Gulch (09306200) between the years 1972 and 1973 is of particular interest (Figure 3-5). The 1973 flow at this station is two times the average flow for the previous eight years. While no more than a tentative hypothesis is made regarding this dramatic increase, it should be noted that the Rio Blanco nuclear test occurred about eight miles west and south of the Tract on May 17, 1973. Figure 3-5 shows stream flow at Piceance Creek above Ryan Gulch (09306200) as monthly average by season for each water year of record and monthly averages by season for precipitation at Little Hills and Meeker. Seasons were selected for presentation to show variations between baseflow and spring and summer


HYDROGRAPH
1975-1976 WATER YEAR
PICEANCE CREEK BELOW RIO BLANCO
USGS 09306007
FLOW, CUBIC FEET PER SECOND
100
50
20
10
5
2
1
1975
1976
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP

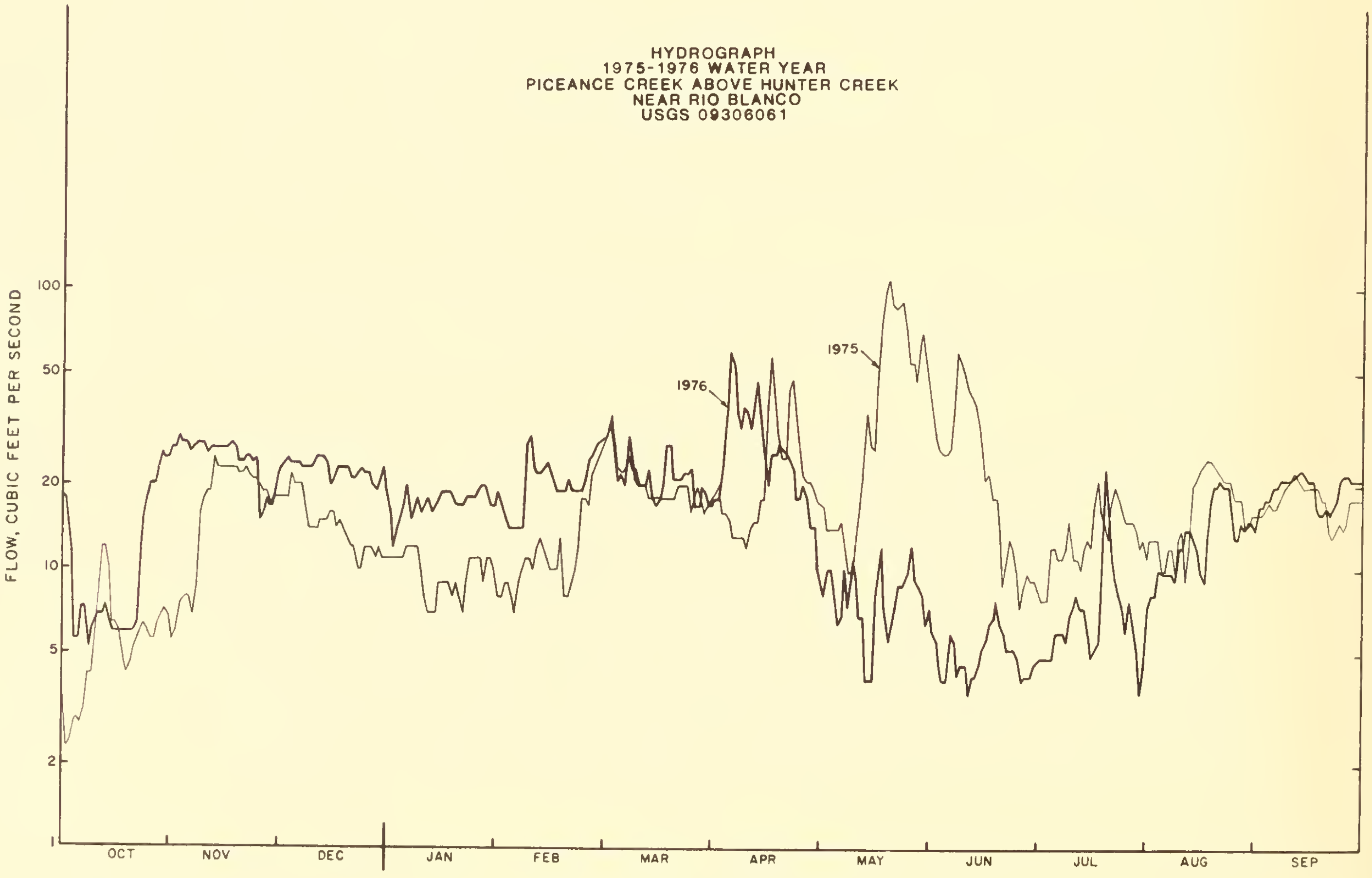
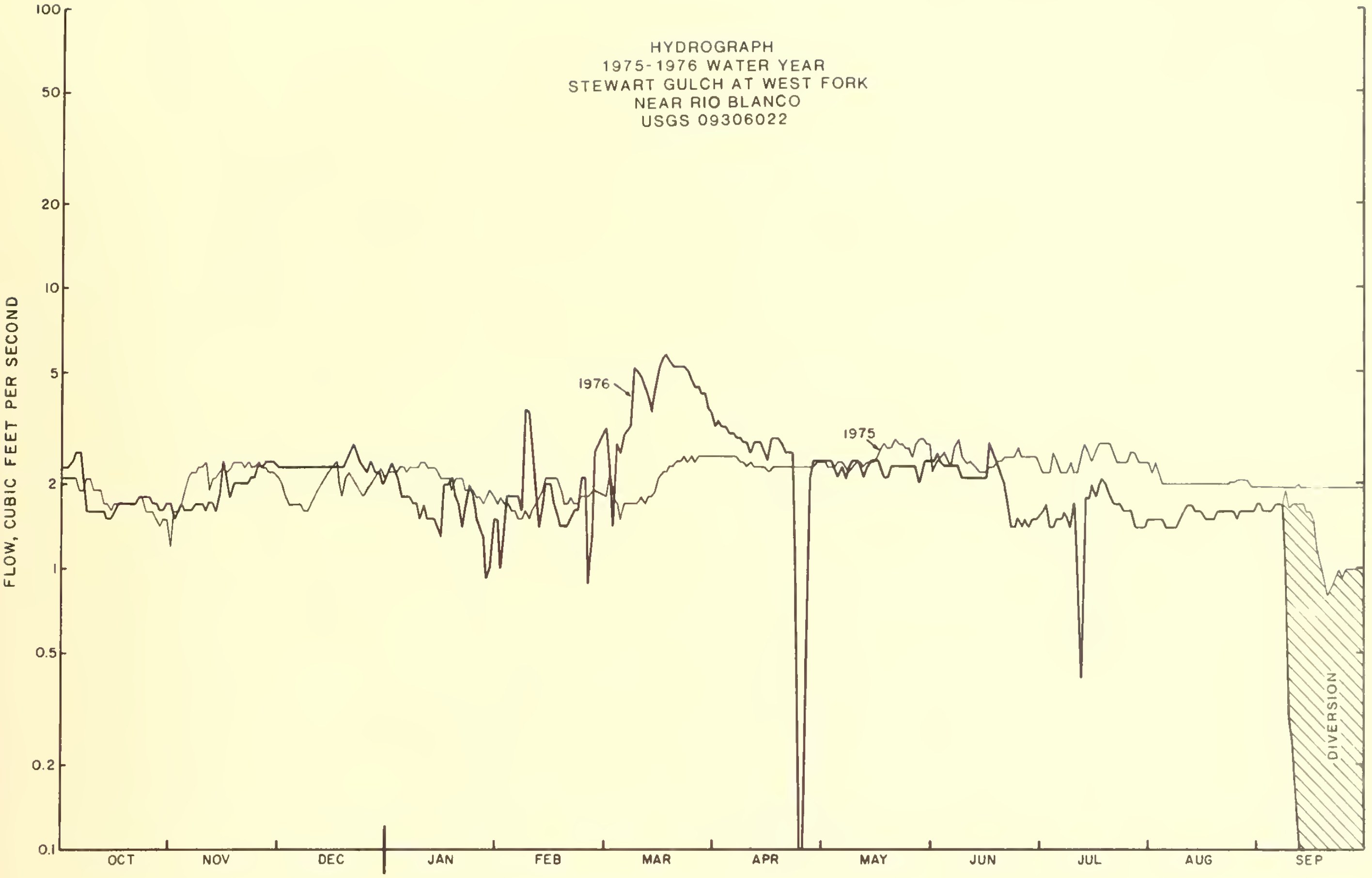

HYDROGRAPH
1975-1976 WATER YEAR
PICEANCE CREEK ABOVE HUNTER CREEK
NEAR RIO BLANCO
USGS 09306061
FLOW, CUBIC FEET PER SECOND
100
50
20
10
5
2
1
1975
1976
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
TIME OF THE YEAR

FIGURE 3-3



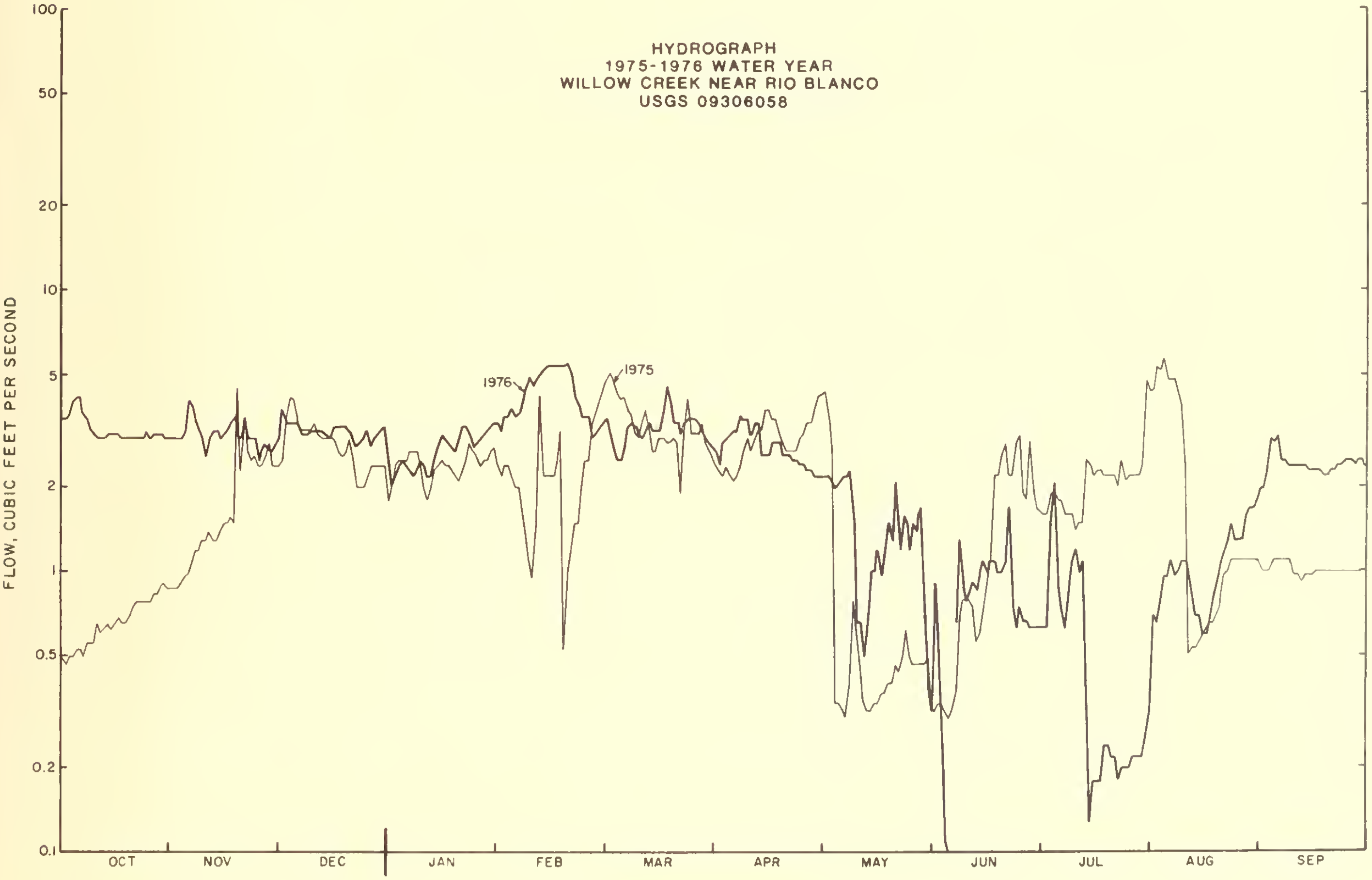


FIGURE 3-4

TIME OF THE YEAR

Table 3-3

IRRIGATION DIVERSIONS IN THE VICINITY OF TRACT C-b
(Irrigation Year November 1974-October 1975)

DIVERSION STRUCTURE	LOCATION	DIVERSION Q (SFD) Apr	May	Jun	Jul	Aug	Sept	Oct
On Piceance Creek								
B&M Ditch (& enl)	T2S R97W Sec 26 SESE (Sec 25 SWSW)	-	10	48	79	60	-	-
Emily Ditch (& enl)	T2S R96W Sec 31 SESE (Sec 31 SESE)	18	100	126	137	37	-	84
Garden Heir Ditch (& enl)	T2S R97W Sec 36 NESE (36 NESE)	None Recorded in 1975						
King Ditch No. 1 (& enl)	T3S R96W Sec 13 NWNE (Sec 13 NWNE)	None Recorded in 1975						
King Ditch No. 2 (& enl)	T3S R96W Sec 13 NENW (Sec 13 NWNE)	30	70	57	47	23	30	-
Oldland Ditch	T3S R96W Sec 12 SWNW	42	173	193	164	108	41	114
Oldland Ditch 2	T3S R96W Sec 11 (NENW)	18	199	215	123	58	-	68
Oldland Ditch 3 (& enl)	T3S R96W Sec 3 NWSW (Sec 3 NWSW)	26	68	44	20	-	-	32
Oldland Major Ditch (& enl)	T2S R96W Sec 32 SWSW (Sec 32 SWSW)	32	118	71	63	25	-	41
P & L Ditch	T2S R97W Sec 35 NENE	-	8	15	73	14	15	16
Piceance Creek Ditch (& enl)	T2S R97W Sec 36 NENE (Sec 36 NENE)	-	251	141	166	0	-	50
Piceance PL & Canal	T3S R96W Sec 4 NWNE	None Recorded in 1975						
Rye Grass Ditch (& enl)	T3S R96W Sec 4 NENW (Sec 3 NWSW)	27	184	136	112	83	-	77
Spaulding Ditch (& enl)	T3S R95W Sec 18 NWNE (Sec 18 NWNW)	29	84	60	55	22	59	74
Upper Ditch	T3S R95W Sec 17	None Recorded in 1975						
Wallace Ditch	T3S R95W Sec 18 NENE	54	50	3	44	31	20	-
Walsh Ditch (& enl)	T3S R95W Sec 18 NWSE (Sec 18 NWNE)	-	33	2	25	54	14	7
On Stewart Gulch								
Blue Grass Ditch	T3S R96W Sec 5 NESE	63	45	49	35	3	19	14
Florence Ditch (& enl)	T3S R96W Sec 16 SENW (Sec 16 NWSE)	-	2	-	-	13	22	13
Jessup Ditch No. 1 (& enl)	T3S R96W Sec 5 SENE (Sec 5 SENE)	-	57	35	36	10	-	26
Jessup Ditch No. 2 (& enl)	T3S R96W Sec 5 SENE (Sec 5 SENE)	-	-	-	-	60	45	16
East Stewart Gulch								
East Stewart Gulch #1		-	3	15	4	1	1	-
East Stewart Gulch #2		-	-	-	10	7	2	1
West Stewart Gulch								
West Stewart Gulch		-	5	8	-	-	-	-
On Willow Creek								
Ebler Ditch	T3S R97W Sec 34 NW	-	6	12	12	-	-	-
Limberg Spring Ditch (& enl)	T2S R97W Sec 35 NENE (Sec 35 NENW)	10	33	22	39	45	5	-
Pile Ditch	T3S R97W Sec 11 NWSE	-	22	64	93	33	12	4
Taylor Ditch	T3S R97W Sec 34 NWSW	13	45	48	46	47	38	23
Willow Creek Ditch No. 1	T3S R97W Sec 2 SESW	-	59	73	0	70	53	18
Willow Creek Ditch No. 2	T4S R97W Sec 34 SESW	-	35	40	73	12	21	44
Willow Creek Ditch No. 3	T4S R97W Sec 33 SESW	-	32	29	20	46	-	-

Table 3-4
YEARLY DISCHARGE SELECTED WATER GAUGING STATIONS PICEANCE CREEK
(in Acre feet)

	Piceance Creek at White River 09306222	Piceance Creek below Ryan Gulch 09306200	Piceance Creek above Hunter Crk 09306061	Piceance Creek below Rio Blanco 09306007	Willow Creek near Rio Blanco 09306058	Stewart Gulch above West Fork 09306022
1965	12,440	11,230				
1966	11,880	9,970				
1967		6,010				
1968		9,470				
1969		13,800				
1970		16,830				
1971	12,580	11,910				
1972	9,520	7,940				
Mean Flow	11,605 (n=4)	10,895 (n=8)				
1973	23,580	21,100				
1974	24,730	19,800				
1975	24,570	21,170	13,690	10,353	1,411	1,520
1976			12,024	7,819	1,745	1,462
Mean Flow	16,614 (n=7)	13,566 (n=11)				

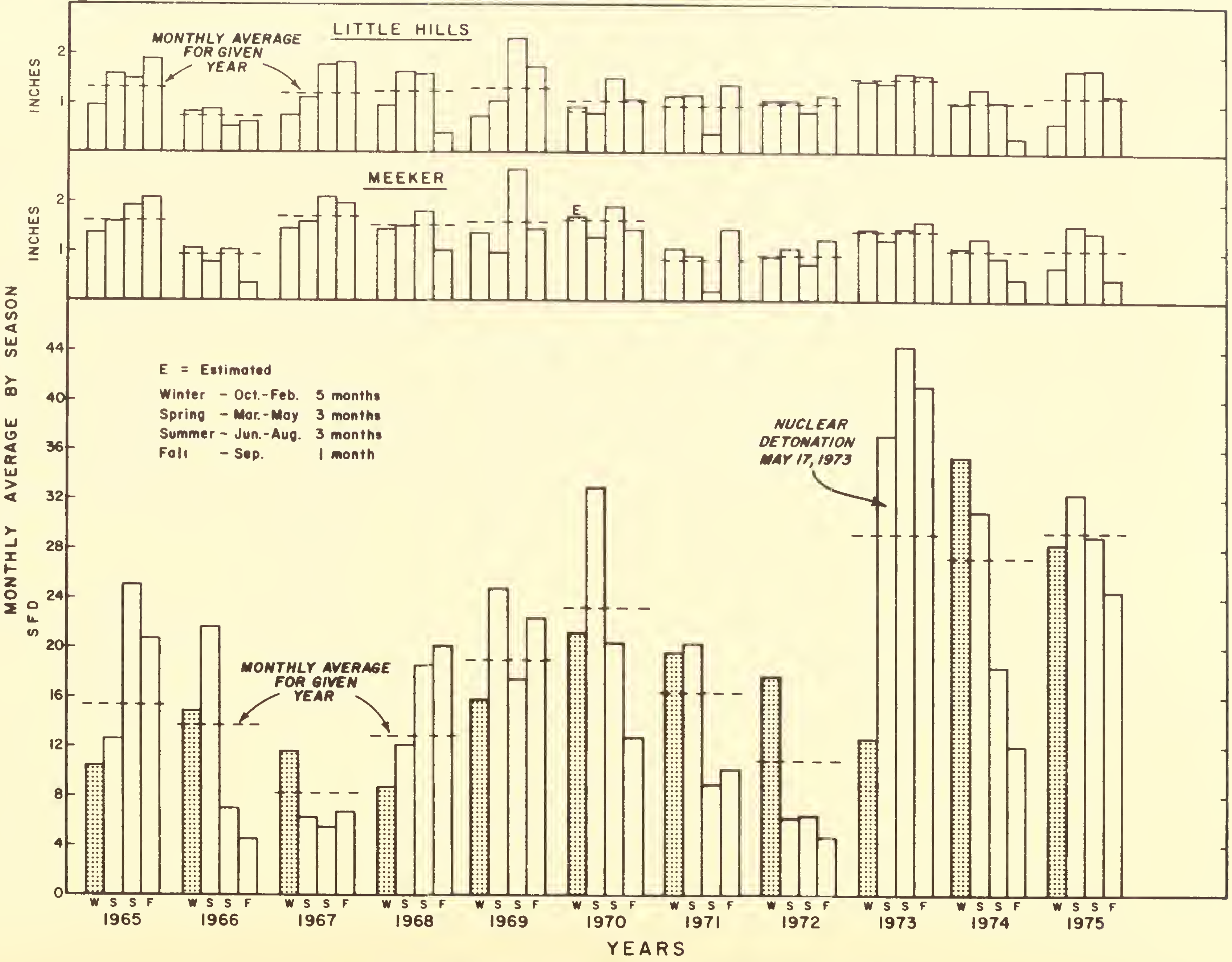


FIGURE 3-5 MONTHLY AVERAGES BY SEASONS FOR STREAMFLOW AT PICEANCE CREEK ABOVE RYAN GULCH, USGS 09306200 AND FOR PRECIPITATION AT LITTLE HILLS AND MEEKER, 1965-1975

runoff. The seasons were chosen as winter, October through February; spring, March through May (usual snowmelt season); summer, June through August (usual convective storm season); and fall, September (usually a return to frontal storms). Dashed lines indicate the level of the yearly average.

Prior to 1973 the seasonal representation indicates a cyclic nature in volume based on what appears to be a six-year return period from trough to trough. The short record does not provide much confidence in this hypothesis. Nonetheless, the dramatic change in the spring of 1973 is evident.

Monthly averages by season for the length of record before and after the nuclear test are shown in Table 3-5. The difference between the before and after flow is quite similar with the exception of the fall averages. This might be explained in part by the lack of fall precipitation in the drainage basin. Both Meeker and Little Hills show a below average September precipitation in 1974 which might account for the 2 cfs lesser difference for the fall readings. Another explanation may be that fall only covers one month of record.

If the long-term stream flow pattern is indeed cyclic as suggested above, it is quite possible that the baseline years for Tract C-b, 1975 and 1976, show a substantially greater than normal flow because the period of maximum flow in the natural cycle occurred at the same time that ground water flows were increased as a result of the nuclear test. Thus, a future decrease from baseline averages for surface water flow in the vicinity of Tract C-b cannot be summarily attributed to operations on the Tract.

Table 3-5

MONTHLY AVERAGES BY SEASON FOR STREAM FLOW
BEFORE SPRING 1973 & AFTER WINTER 1973

Stream Flow in cfs

SEASON	BEFORE*	AFTER	DIFFERENCE
Winter	14.8	30.9	16.1
Spring	17.1	33.6	16.5
Summer	13.7	30.6	16.9
Fall	12.8	26.0	14.2

* Before winter averages include 1965 to 1973 since test did not occur until Spring 1973. All the rest are 1965 to 1972.

The abrupt change of annual streamflow at Ryan Gulch is also shown on a double mass curve (Figure 3-6). In this projection, the accumulated mean monthly discharge at Piceance Creek below Ryan Gulch was plotted against the average accumulated discharge at two stations on the White River. Figure 3-6 definitely shows a deviation after 1972. The deviation, in fact, continues to 1975, the last year of record.

In addition to the yearly average, variations of stream flow about the average are important. Such variations are daily, seasonal, and yearly. To some extent, these variations are regional characteristics with the size of the drainage basin being a local variable.

Figure 3-7 shows the ratio of maximum annual streamflow to mean annual streamflow as a function of the drainage basin area. On the same figure is a curve showing the ratio of maximum peak flow to average flow. The first curve shows a lesser effect owing to area than the peak/average flow ratio; however, it is evident that substantially higher ratios are associated with the smaller basin areas. The peak/average flow ratio can be thought of as an expression of responsiveness of the basin. It shows the reaction of a basin to a precipitation event large enough to increase the flow over normal and this responsiveness increases as basin size decreases.

Mean monthly stream flow for the period of record for Tract stations and Piceance Creek stations is shown in Figure 3-8. The lower Piceance Creek stations are trimodal with peaks in the late fall, early spring, and summer. Two-year averages on Stewart Gulch and Willow Creek show different characteristics as do the stations on Piceance Creek above and below the Tract. Individual tributaries above the Ryan Creek Station must vary as to the month of maximum flow in order for the patterns of the monthly hydrographs of the lower main stream stations to exhibit a trimodal pattern. This would imply a different character for different areas of the Piceance Creek basin. However, the short period of record could be contributing to erroneous conclusions.

Table 3-6 shows the five greatest yearly peaks of instantaneous flow for selected stations on Piceance Creek and White River for the length of record. It also shows the yearly peaks for stations in the Tract area for the baseline period. Figure 3-9 shows yearly maximum flows for the period of record. The shape of the curves for three years of data (1974 was arbitrarily selected as one year since the maximum peak of record was obtained in July 1974) at 09306007 and 09306061 approximates the shape of the curve for Piceance Creek below Ryan Gulch (11 years record) and Piceance Creek at White River (7 years record). It appears that each curve belongs to the same family of curves. Projection of curves for 09306007 and 09306061 would indicate that the ten-year instantaneous peak flow would be about 325 cfs.

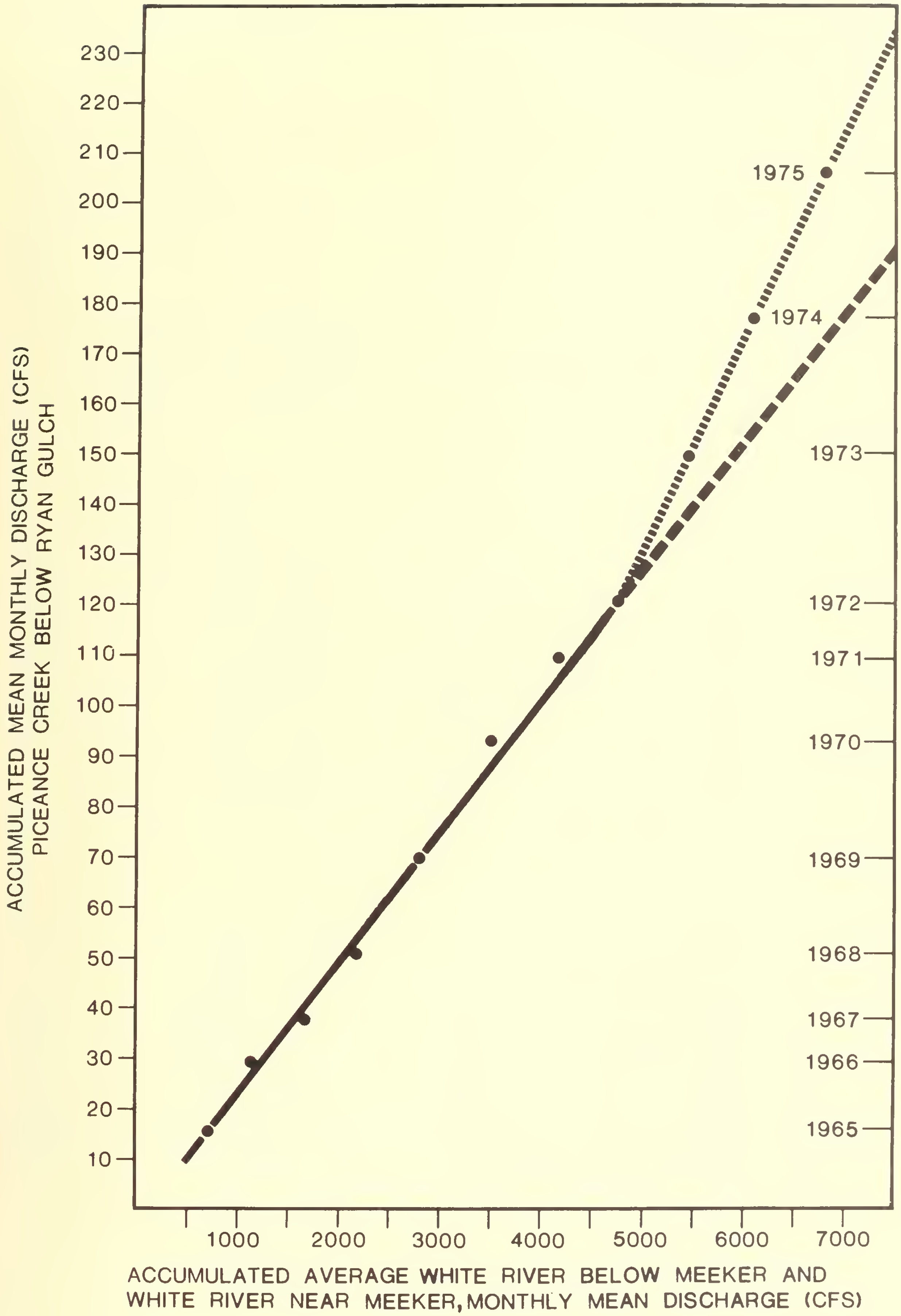
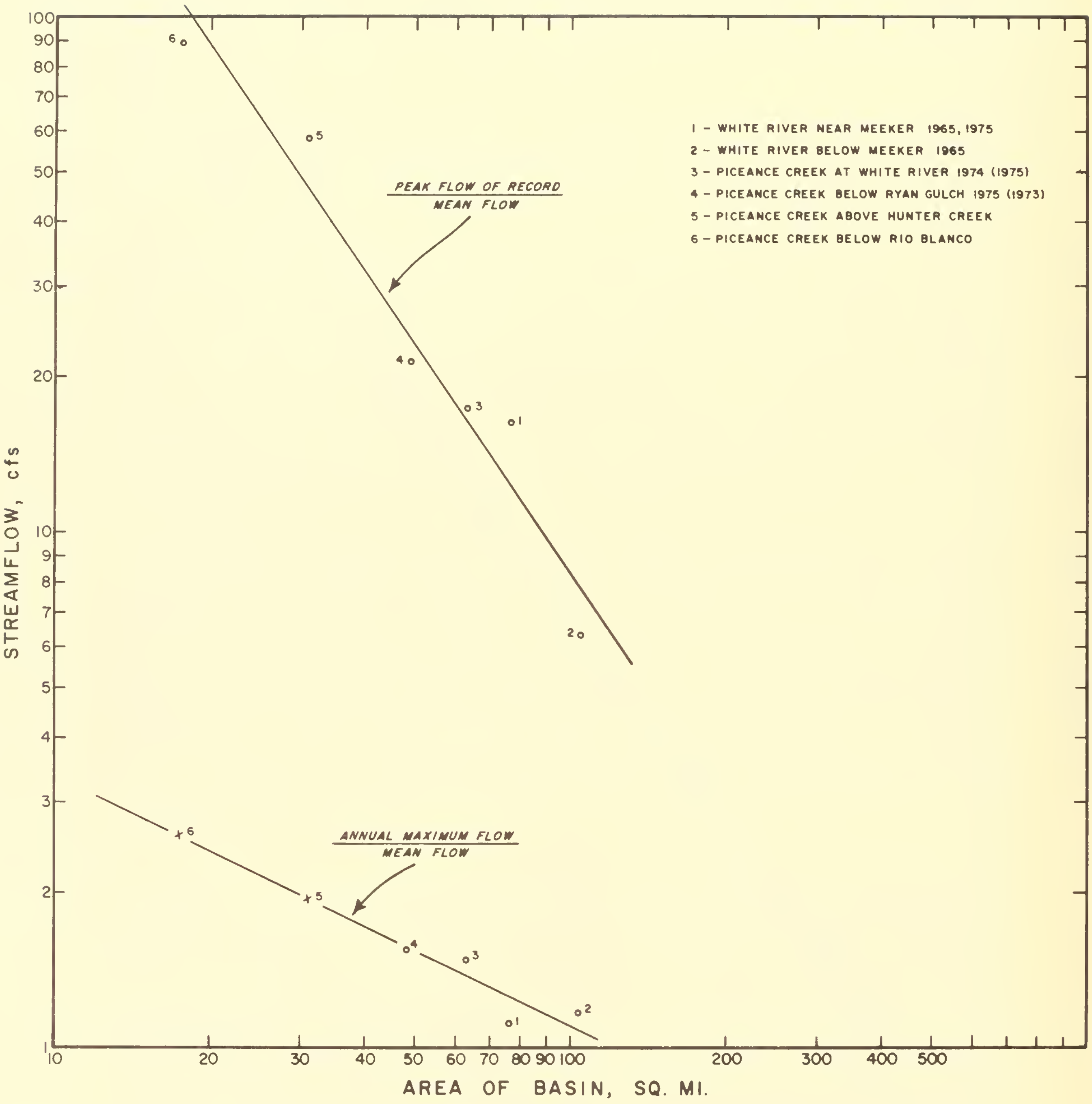
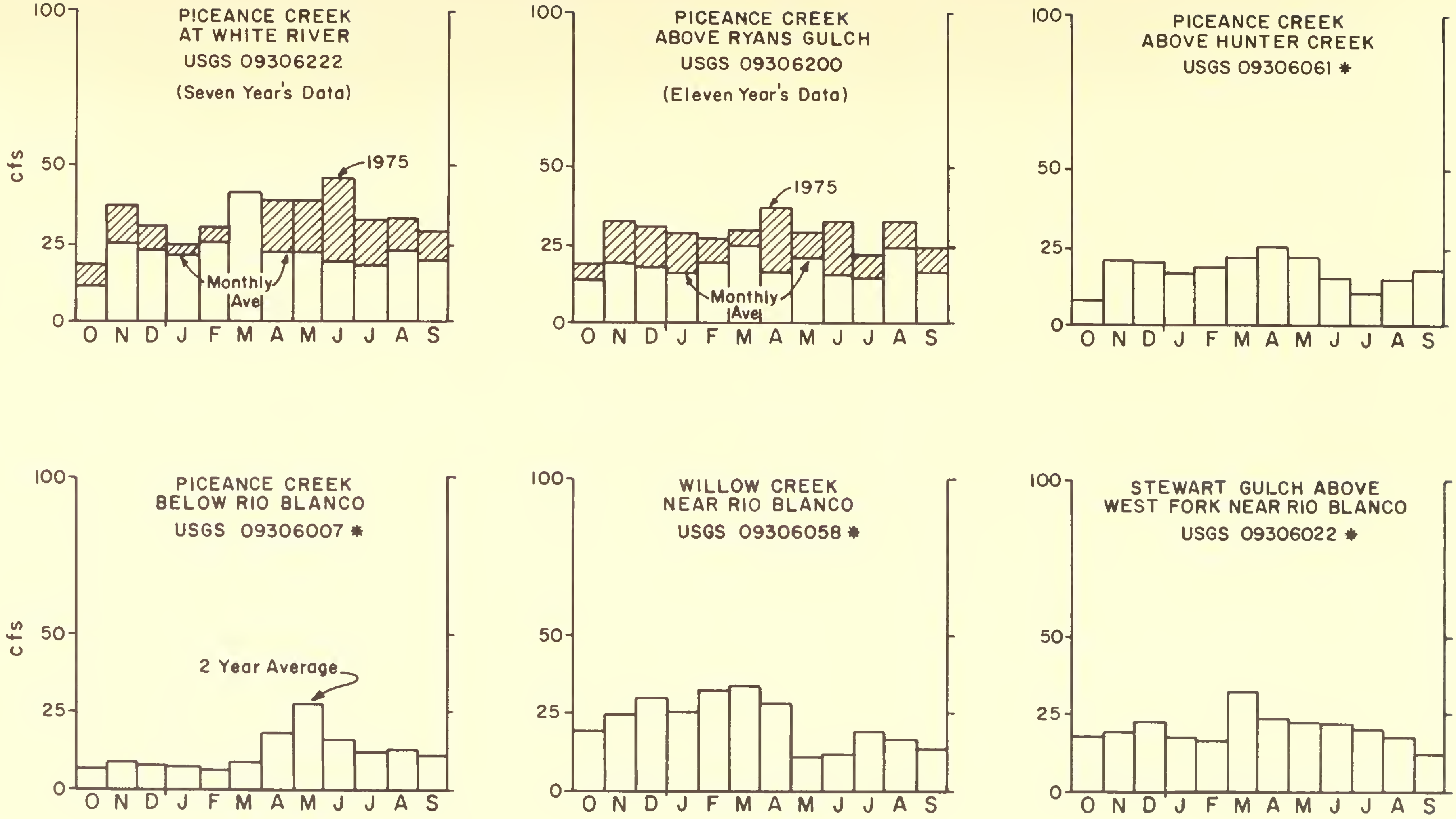


FIGURE 3-6 **DOUBLE MASS CURVE**



PEAK FLOW / MEAN FLOW & ANNUAL MAXIMUM FLOW / MEAN FLOW
FOR SELECTED STATIONS IN WHITE RIVER & PICEANCE CREEK

FIGURE 3-7



* Two years of Data
1975 & 1976

FIGURE 3-8 MEAN MONTHLY STREAMFLOW
FOR SELECTED STATIONS ON PICEANCE CREEK

Table 3-6

PEAK FLOW & RETURN PERIOD FOR SELECTED STATIONS, PICEANCE BASIN

WHITE RIVER NEAR WATSON				WHITE RIVER NEAR MEEKER				WHITE RIVER BELOW MEEKER			
R	Q	Yr (60)	Tr	R	Q	Yr (71)	Tr	R	Q	Yr (74)	Tr
1	8160	7/15/29	61	1	6370	6/16/21	72	1	4370	6/08/75	75
2	6830	7/25/65	30	2	4230	6/08/75	36	2	4010	6/15/65	8
3	5650	3/11/66	6	3	4030	6/15/75	6	3	3990	5/21/70	5
4	4200	5/22/73	4	4	4010	5/21/70	4	4	3700	3/07/68	4
5	4150	5/21/21	3	5	3910	5/21/73	3	5	3660	5/21/73	3

PICEANCE CREEK AT WHITE RIVER				PICEANCE CREEK BELOW RYAN				PICEANCE CREEK ABOVE HUNTER				PICEANCE CREEK BELOW RIO BLANCO			
R	Q	Yr (7)	Tr	R	Q	Yr (11)	Tr	R	Q	Yr (3)	Tr	R	Q	Yr (3)	Tr
1	407	3/09/66	8	1	400	3/09/66	12	1	155	7/26/74	4	1	152	7/20/74	4
2	284	7/20/73	4	2	211	3/27/71	6	2	95	5/18/75	2	2	104	5/19/75	2
3	242	3/27/71	3	3	190	8/19/65	4	3	82	4/05/76	1	3	79	7/19/76	1
4	174	6/24/65	2	4	184	7/28/68	3								
5	153	7/15/75		5	141	3/18/69									

R = Rank

Q = Peak Flow

Yr = Date of Peak Flow; (years of record)

Tr = Return Period = $\frac{\text{No. years of Record + 1}}{\text{Rank of Peak Flow}}$

(From Linsley, et al. 1958)

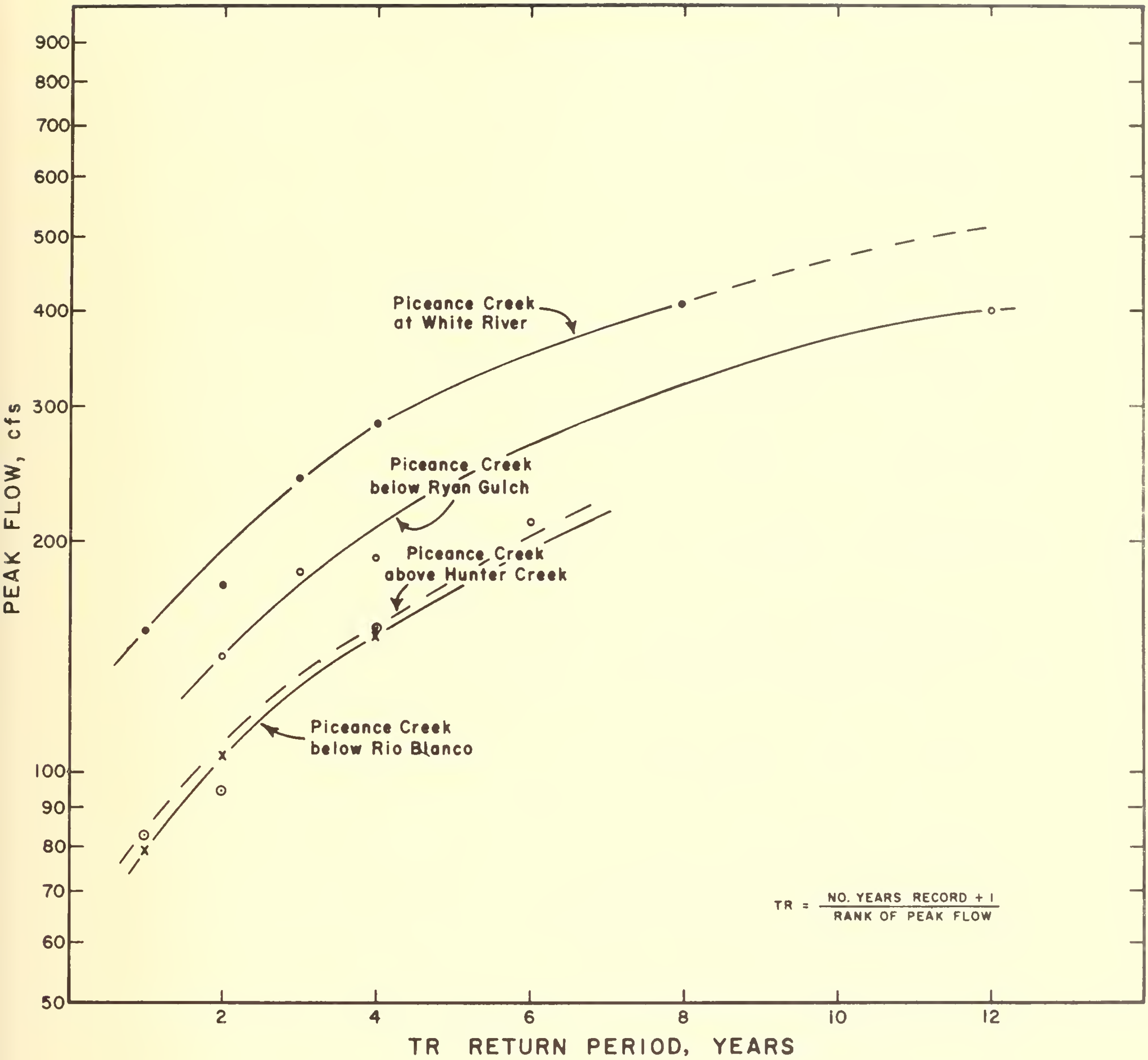


FIGURE 3-9 PEAK FLOW RETURN PERIOD

3.1.1.5.3 Summary and Conclusions

Stream flow in the Piceance Creek basin depends on outflow from seeps and springs for baseflow. Early spring peaks in stream flow are caused by melt water from the winter snow pack. Monthly data show the maximum monthly peak in March; daily peaks occur not only during the snow melt season, but also during the summer as the result of convective storm activity.

The annual stream flow regime, particularly the baseflow fraction, on Piceance Creek and its tributaries in the vicinity of the Tract may have changed considerably since the Rio Blanco nuclear test in 1973. The effect of this underground explosion on baseflow in the region of the Tract is unknown since records cover only two and one-half years. Baseflow at the station above Ryan Gulch doubled after the test, but to date, there has been no published report correlating the nuclear test with this change in flow. If the test did cause this change in flow regime in the Tract area, the possibility exists that baseflow will gradually return to pre-1973 conditions. Thus, a major decrease in stream flow across the Tract at some future time may not be the result of oil shale operations but a recovery from the effects of the nuclear test. At best, it will be difficult to separate out the effects of the nuclear test.

Two and one-half years of data are not sufficient to make any definitive analyses. At least ten years of data are desired to make firm conclusions concerning stream flow and basin characteristics.

3.1.2 Sediment Analysis

3.1.2.1 Rationale for Measurement

Sediments carried by surface streams reflect the surrounding environment and can be sensitive indicators of a variety of man's activities. Changes in quantity and character of sediment are often a major impact resulting from construction and development activities. Increased erosion from cut and fill areas or from temporarily piled material is the most obvious mechanism for such changes. More subtle changes in characteristics can result from atmospheric emission of insoluble trace metals or compounds thereof. Such materials can then be manifested in the sediments being carried by surface run-off waters. Any attempt to assess such effects by the analysis of sediments will require a knowledge of natural characteristics, or baseline conditions, in the area under study.

3.1.2.2 Objectives

The objective of this effort was to provide a baseline characterization of the chemical, physical, and mineralogical properties of stream bed sediments in the major drainages from Tract C-b. This characterization should be in sufficient detail to allow a later differentiation from development-related sediments if changes occur. As a part of this procedure, samples were stored for future comparison, and analysis by additional techniques if the need arises.

3.1.2.3 Experimental Design

One composite sample each from Piceance Creek, West Fork Stewart Gulch, Sorghum Gulch, Cottonwood Gulch, the unnamed gulch west of Cottonwood, Scandard Gulch, and Willow Creek were collected, analyzed, and stored for future reference.

3.1.2.4 Methodology

Samples of fine streambed sediments were obtained from each of the major drainages. Where possible, the material was collected from deposits which were obviously the result of recent deposition. This was feasible in the case of West Fork Stewart, Sorghum, and Cottonwood Gulches where recent storms had caused runoff which resulted in new deposits near the mouth of these tributaries. In every case an attempt was made to collect the finest material visible and a composite sample was assembled from the surface layers of all easily located deposits.

In the case of Scandard Gulch and the unnamed gulch west of Cottonwood, (at alluvial well A-5 and water gauging Station 09306042) little or no flow has occurred during the baseline data-gathering period (Figure 3-1). Fine surficial sediments deposited as a result of flow in previous years have probably been altered by wind. Because of this, these samples were collected at random from the streambed (again attempting to collect the finest material available) over a distance of about 300 yards from the gauging stations. Surface material was not used in order to minimize the influence of recent aeolian deposits, if any.

For the flowing streams, Willow Creek at mouth and Piceance Creek below Cottonwood, samples were collected from the stream bottom in such a way as to be comparable to the Cottonwood, Sorghum, and West Stewart samples. That is, only recently deposited sediments were used (as determined by differentiation of color and compaction, and relationships to vegetation in shallow back-water areas). Approximately one gallon was collected at each site. Samples were air-dried where necessary, then passed through a 1/16" mesh sieve to remove any pebbles and trash. Each sample was then blended thoroughly by repeated passes through a riffle box.

A portion of each sample was retained for future reference.

All samples were analyzed by Agricultural Consultants, Inc. for particle size distribution, total major elements, and total trace elements. Particle size distributions were determined by hydrometer techniques. X-ray diffraction analyses of the as-received samples were conducted by the Colorado School of Mines Research Institute. The Sorghum Gulch sample was ground to minus 200 mesh and subjected to detailed x-ray diffraction analyses and scanning electron microscopy by the Denver Research Institute.

3.1.2.5 Results and Discussion

3.1.2.5.1 Particle Size Analysis

Particle size distributions are listed in Table 3-7 and plotted in Figure 3-10. The major portion of all samples falls into the fine sand to silt range. The frequency distribution curves (Figure 3-10) are similar for all except the West Fork Stewart Gulch sample. This sample is composed of appreciably finer particles than the other samples and exhibits a narrow particle size range, such as might be produced by wind-sorting. The Scandard Gulch and unnamed gulch samples show the lack of small sized particles which was noted in the methodology discussion.

3.1.2.5.2 Chemical Analysis

Chemical analyses for major constituents are given in Table 3-8. The West Fork Stewart Gulch sample appears slightly atypical only with respect to a higher organic content than the other samples. Mineral element distributions for all samples are very similar and no unusual values are seen.

Analyses for trace elements are listed in Table 3-9. As would be expected, larger sample-to-sample variations are evident than for the major constituent analyses. The Sorghum Gulch values for arsenic, fluorine, lead, and nickel are not compatible with the other samples and should be considered suspect.

Mean values from Tables 3-8 and 3-9 are listed in Table 3-10 along with other results of interest. Columns (2) and (3) are mean values determined for Duck Creek and Ryan Gulch in the Piceance Creek basin. The USGS study from which these values were taken concluded that significant differences can be found between streams. All the C-b values for major constituents in Table 3-10 fall within the expected 95 percent range for the Duck Creek or Ryan Gulch data. However, four of the six trace element values fall outside the 95 percent range, indicating that sediment origins could perhaps be determined by means of trace element analysis. This would provide a major justification for chemical analysis.

Table 3-7

PARTICLE SIZE ANALYSES

SAMPLES	Weight Percent for Given Particle Size Range, Millimeters					
	(A) 1.-.5	(B) .5-.25	(C) .25-.1	(D) .1-.05	(E) .05-.002	(F) <.002
Sorghum Gulch	10	29	31	11	18	1
Cottonwood Gulch	3	18	34	14	28	4
Unnamed Gulch	7	5	50	31	13	2
Scandard Gulch	11	19	14	33	22	1
West Fork Stewart	0	0	8	24	64	5
Piceance Creek	16	17	29	11	24	3
Willow Creek	3	11	36	14	32	4

(A) Coarse sand
(B) Medium sand
(C) Fine sand
(D) Very fine sand
(E) Silt
(F) Clay

Note: Classification system from American Society of Agronomy, "Methods of Soil Analysis"

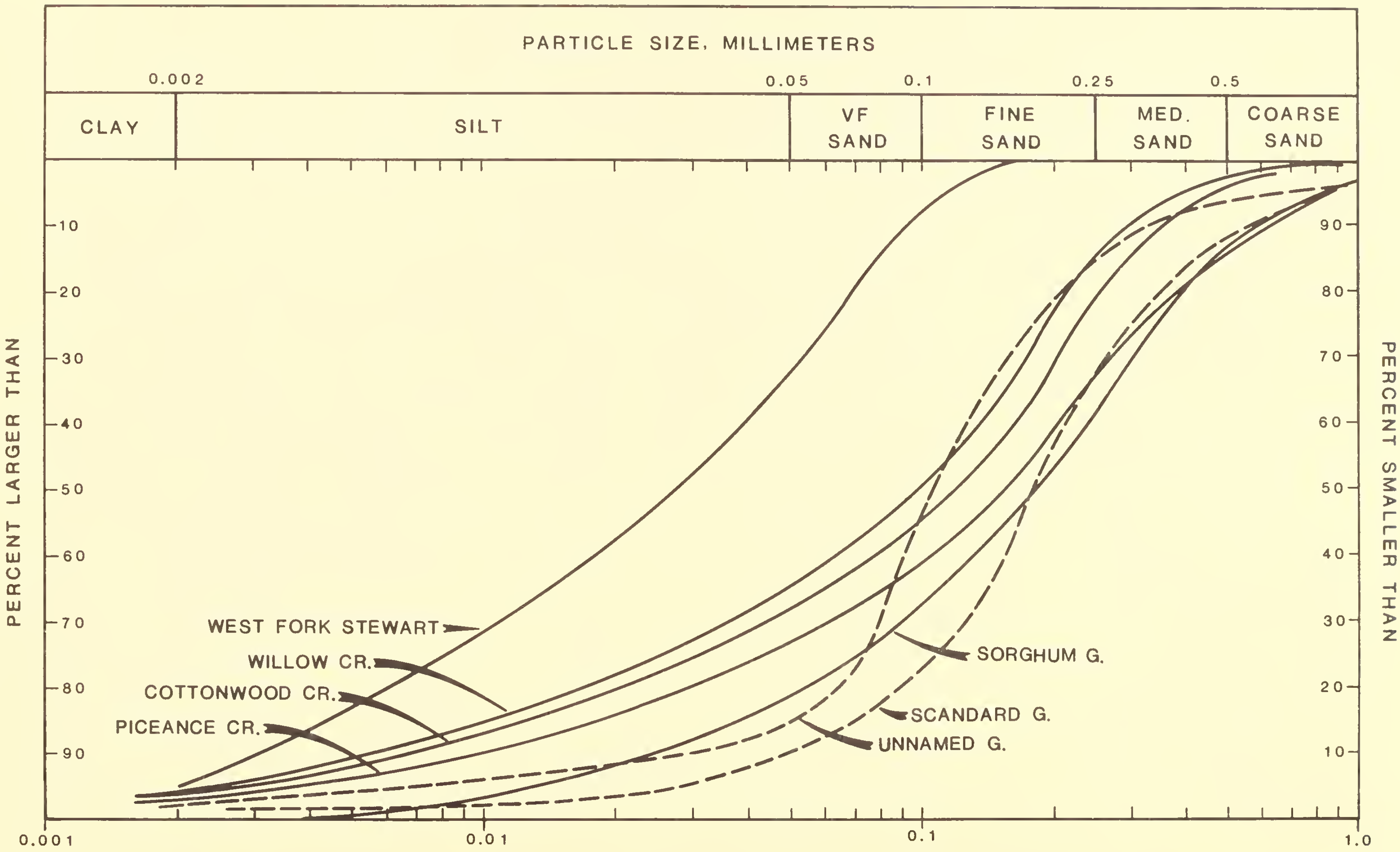


FIGURE 3-10 PARTICLE SIZE DISTRIBUTIONS

Table 3-8

MAJOR ELEMENT ANALYSES

CONSTITUENT	Sample Weight Percent*						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Organic Material	2.67	4.5	3.6	3.1	5.9	2.1	3.0
Fe_2O_3	2.9	1.1	1.3	1.6	1.2	1.3	1.6
Silicon	32.0	29.5	27.6	30.3	30.4	28.0	29.4
Aluminum	9.1	9.3	9.2	9.4	8.2	10.5	9.3
Calcium	2.5	3.6	5.2	2.4	2.4	2.2	2.6
Magnesium	0.9	0.9	0.96	0.75	0.95	0.85	0.74
Sodium	2.7	3.2	4.6	3.2	3.8	4.8	4.2
Potassium	1.0	1.7	2.6	1.7	1.8	2.4	1.8
Iron	2.0	4.0	3.6	4.0	4.4	4.0	3.8
Titanium	0.46	0.28	0.21	0.29	0.36	0.23	0.34

Sample Key

(1) Sorghum Gulch
(2) Cottonwood Gulch
(3) Willow Creek
(4) Unnamed Gulch
(5) West Fork Stewart
(6) Scandard Gulch
(7) Piceance Creek

* Balance of material assumed to be oxygen

Table 3-9

TRACE ELEMENT ANALYSES

CONSTITUENT	Sample, PPM						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Arsenic	-0.1	4.3	6.1	5.2	7.3	6.4	7.8
Barium	260.	730.	270.	280.	210.	290.	270.
Boron	26.	19.	13.	16.	21.	18.	16.
Cadmium	-0.1	0.1	0.2	0.1	0.1	0.2	0.1
Chloride	21.	33.	68.	41.	76.	83.	42.
Chromium	2.4	3.9	3.1	3.7	4.3	2.6	2.1
Cobalt	-1.	4.	6.	5.	9.	4.	7.
Copper	11.	13.	11.	12.	13.	11.	11.
Fluoride	2.	360.	280.	310.	340.	450.	310.
Lead	-0.1	28.	25.	27.	27.	24.	26.
Manganese	410.	960.	910.	840.	1600.	1700.	1700.
Mercury	-0.01	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
Molybdenum	-0.1	0.4	1.1	1.3	1.6	0.9	1.0
Nickel	200.	78.	36.	32.	54.	18.	27.
Phosphorus	620.	740.	680.	860.	730.	670.	720.
Selenium	-0.01	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
Sulfur	32.	46.	38.	52.	77.	41.	44.
Vanadium	16.	18.	21.	17.	19.	16.	19.

Sample Key:

(1) Sorghum Gulch
(2) Cottonwood Gulch
(3) Willow Creek
(4) Unnamed Gulch
(5) West Fork Stewart
(6) Scandard Gulch
(7) Piceance Creek

\- means less than

Table 3-10

COMPARISON OF CHEMICAL ANALYSES

ELEMENT	(1) C-b Sediment	(2) Duck Creek Sediment	(3) Ryan Gulch Sediment	(4) Piceance Basin Soils	(5) C-b Air Particulates
Silicon, %	30.			26.	2.0
Aluminum, %	9.3			5.5	0.3
Calcium, %	3.0	7.5	3.0	1.9	1.5
Magnesium, %	0.86	0.95	0.68	1.0	4.8
Sodium, %	3.8	1.8	2.5	1.4	5.1
Potassium, %	1.9	2.0	2.0	2.3	0.8
Iron, %	3.7	1.7	2.4	1.8	4.1
Titanium, %	0.3			0.3	0.1
Arsenic, ppm	5.3			6.4	46.
Barium, ppm	330.			1400.	160.
Boron, ppm	18.			61.	530.
Cadmium, ppm	0.13				3.8
Chlorine, ppm	52.				441.
Chromium, ppm	3.2			60.	38.
Cobalt, ppm	5.1	5.9	8.	7.9	7.8
Copper, ppm	12.			29.	
Fluorine, ppm	290.			490.	3580.
Lead, ppm	22.	13.	19.	26.	187.
Manganese, ppm	1200.	615.	480.	490.	880.
Molybdenum, ppm	0.9			5.3	7.2
Nickel, ppm	64.			21.	10.
Phosphorus, ppm	720.				4600.
Sulfur, ppm	47.				2030.
Vanadium, ppm	18.	73.	120.	56.	185.

(1) C-b Sediment Analyses, This Study, average of all samples
(2) Duck Creek Sediment, USGS Open File Report 76-729
(3) Ryan Gulch Sediment, USGS Open File Report 76-729
(4) Piceance Basin Soils, USGS Open File Report 76-729
(5) C-b Air Particulate Analyses, Mean of Five Quarters

Column 4, Table 3-10 lists mean values for approximately 140 samples of surface soils in the Piceance Creek basin, as given in USGS Open File Report 76-729, "Geochemical Survey of the Western Energy Regions." Significant differences appear for barium, boron, and chromium. In each case, the mean value for total trace metals of C-b sediments is below the lower limit of the observed values for soils.

Column 5 of Table 3-10 contains average values for the analysis of air particulates on C-b by Radian Corp. When averaged over a wide area, one might expect a correlation between dust and sediment. The air analyses, however, appear to carry little resemblance to the sediment or soil analyses. The air analyses have shown widely fluctuating results. At this time it would appear that little or no correlation exists between dust and sediment. This could indicate that dust, at least that which accumulates during periods of heavy atmospheric dust loading, is being blown onto Tract C-b from long distances away.

3.1.2.5.3 Mineral Analysis

Powder diffractometer scans of the as-received samples showed the presence of the following phases:

Major: Quartz - SiO_2

Feldspar - $NaAlSi_3O_8$

Minor: Montmorillonite - $(Na,Ca)_{.33}\ (Al,Mg)_2$

$Si_4O_{10}\ (OH)_2 \cdot nH_2O$

Dolomite - $CaMg\ (CO_3)_2$

Analcime - $NaAlSi_2O_6 \cdot 2H_2O$

Calcite - $CaCO_3$

Inspection of grain mount thin sections under a petrographic microscope revealed the following textural and mineralogical information:

Lithic Fragments: Undecomposed fragments of rock of two types occur:

(1) Those of obvious sedimentary parentage. These consist of feldspar and quartz grains still cemented together by clays and calcite. These composite grains have not yet been mechanically broken down into their mono-mineralic constituents.

(2) Fragments of igneous parentage. These consist of intergrown laths of plagioclase feldspar suggesting a plagioclase-rich igneous parent such as a diabase. These fragments have not yet been broken down into grains consisting of single crystals.

Carbonates: Calcite and dolomite both occur as irregularly shaped small grains. In addition, calcite occurs as a cement in some of the lithic fragments and as rims around quartz grains.

Feldspars: Both plagioclase and alkali feldspar occur in these sediments. Plagioclase is predominant over orthoclase. Most of the feldspars are still locked in the lithic fragments, both types occurring in the fragments of sedimentary parentage and plagioclase being the only feldspar in the fragments of igneous parentage. About 15-20 percent of the feldspars occur as discrete grains altering to mica and clays.

Analcime: Occurs as discrete grains generally free from alteration or inclusions.

Quartz: Occurs in several modes. First, as large discrete grains sometimes associated with calcite; second, as particles consolidated in the lithic fragments of sedimentary parentage; and last, as large discrete grains of chert. For the purposes of the point count, quartz and chert were counted together.

Hornblende: Occurs as small, discrete green grains, free from any alteration or inclusions.

Quantitative information obtained from the point counts on thin sections is summarized in Table 3-11.

The Sorghum Gulch sample was subjected to a more detailed characterization. The sample was coned and quartered, ground and sieved through a -200 mesh Tyler mesh and these samples were subsequently used for X-ray analysis as well as electron and optical microscopy. In order to ascertain accurately the minerals constituting the sample, a heavy density media separation was performed and the concentrates examined. The bulk X-ray analysis showed the presence of alpha quartz, labradorite (plagioclase feldspar group) and analcime (zeolite group). Two heavy density media separations were performed using liquids of densities 2.45 and 2.90. Analysis of the lighter than 2.45 concentrate of solids gave strong peaks of analcime. The heavier than 2.45 solids showed strong diffraction peaks of alpha quartz and labradorite. Solids heavier than 2.90 gave significant diffraction peaks for tremolite and hornblende. Results are listed in Table 3-12.

Thin sections were prepared and examined under an optical microscope and a scanning electron microscope. X-ray microelemental analysis showed that 50 percent of the particles

Table 3-11

PETROGRAPHIC MICROSCOPE

SAMPLE	Phase, Volume Percent					
	Lithic Fragments	Quartz (plus Chert)	Feldspars	Carbonates	Analcime	Hornblende
Sorghum Gulch	48.9	23	21.6	3.4	N.D.	1.2
Cottonwood Gulch	40.0	25	24.0	7.0	3.0	1.0
Unnamed Gulch	31.0	36	13.0	9.0	9.0	2.0
Scandard Gulch	69.0	11	10.0	9.0	1.0	0.4
West Fork Stewart	45.0	25	3.0	16.0	10.0	1.0
Piceance Creek	45.0	20	11.0	12.0	10.0	2.0
Willow Creek	30.1	22	12.5	28.3	5.8	1.0

Table 3-12

SORGHUM GULCH QUANTITATIVE X-RAY DIFFRACTION RESULTS

Compound	Formula	Specific Gravity	Wt. Percent Run #1	Wt. Percent Run #1	Mean Wt.%
∝ - Quartz	$\propto Si0_2$	2.69	57.2	58.5	57.8
Analcime	$NaA\ell Si_20_6 \cdot H_20$	2.27	4.5	5.5	5.0
Labradorite	$Ca_{.7}Na_{.3}A\ell_{1.7}Si_{2.3}0_8$	2.71	37.8	35.5	36.6
Hornblende	$Ca_2(Mg,Fe)_5(SiA\ell)_80_{22}(OH)_{22}$	3.20	0.50	0.5	0.5
Tremolite	$Ca_2Mg_5Si_80_{22}(OH)_2$	3.10			

were found to contain no metals other than silica, indicating that they were quartz particles. Individual particles of quartz, analcime, labradorite, and hornblende were located and photographed.

The significant goal of this effort was to establish the properties of existing stream-bed sediments for later comparison if needed. The detailed chemical and mineralogical analyses used should provide a comprehensive background characterization.

3.1.3 Springs and Seeps

3.1.3.1 Rationale

The flow of natural seeps and springs provides a substantial fraction of low level stream flows in Piceance Creek. Springs are utilized by wildlife, for domestic water sources, and for irrigation. Man-made impoundments around spring sources provide a habitat for varied forms of aquatic life. Although none of the springs studied is actually located on the C-b Tract, they are close enough to be affected by changes to the ground water system caused by mining activities. Any effects on spring flows or water quality will depend on the hydrological relationships, which are largely unknown. Besides the obvious possible effect of reduced spring flows due to mine dewatering, changes in the water quality may be just as important. All water sources in the C-b area are of marginal quality for many uses, and any degradation could reduce the beneficial use of spring waters.

3.1.3.2 Objectives

The immediate objective of this task was to accumulate baseline data on quantity and quality of spring flows. An estimate of the natural variability of these parameters is required in order to be able to assess any future changes.

A second-level objective was to determine, if possible, the likely source of the spring flows. The effect of mining activities will depend very heavily upon which geological stratum supplies the base flow. A computer simulation would require this information before making any attempt to predict environmental changes.

3.1.3.3 Experimental Design

Spring flows in the C-b area are monitored on a regular basis through a cooperative effort between the U. S. Geological Survey and the Colorado Division of Water Resources. Parshall flumes have been installed on most of these springs with significant flows. Unfortunately, many of these springs are utilized for irrigation in such a way that flow is diverted away from the flumes or water from other sources diverted through the flumes for long periods of time.

One attempt was made to obtain precise daily measurements of a spring flow to see if short-term variations could be correlated with barometric pressure.

Figure 3-11 shows the locations of springs and seeps near the Tract. As noted earlier, no significant springs or seeps have been found on the Tract itself. Table 3-13 gives the locations of springs studied by the Division of Water Resources and their correspondence to those shown in Figure 3-11.

Samples of water for chemical analysis were obtained from all the springs shown. Two springs, S-3 and S-9, were selected for detailed study and sampled in February, April, May, June, July, August, and October of 1976 so that short-term fluctuations could be analyzed.

3.1.3.4 Methodology

Spring flow measurements are made with standard Parshall flumes. The only measurement necessary is the water depth in the upstream section. This is read from a scale permanently attached to the side of the flume. Flow readings can be affected if debris is allowed to build up in the flume. After removal of debris, several hours may be required for equilibrium flow to be established, especially in cases where the flume is installed at the outlet of a pond.

One set of more precise daily flow data was obtained at spring S-9 by installing a turbine type flowmeter downstream from the flume. Water from the flume dropped into a plastic barrel to which was bolted approximately 10 feet of 6-inch pipe in two sections. A 6-inch in-line flanged Sparling flowmeter was placed between the two pipe sections. Readings were taken approximately once a day and an average flowrate computed for the elapsed time period.

Samples for chemical analysis were taken from the Parshall flume for all springs having a flume installed close to the spring itself. An exception was spring S-3 where a wide flume and relatively low flow made it inconvenient to try to sample from the shallow depth available. An upstream point was used in this case. All samples were filtered through a 0.45 micron filter in the field.

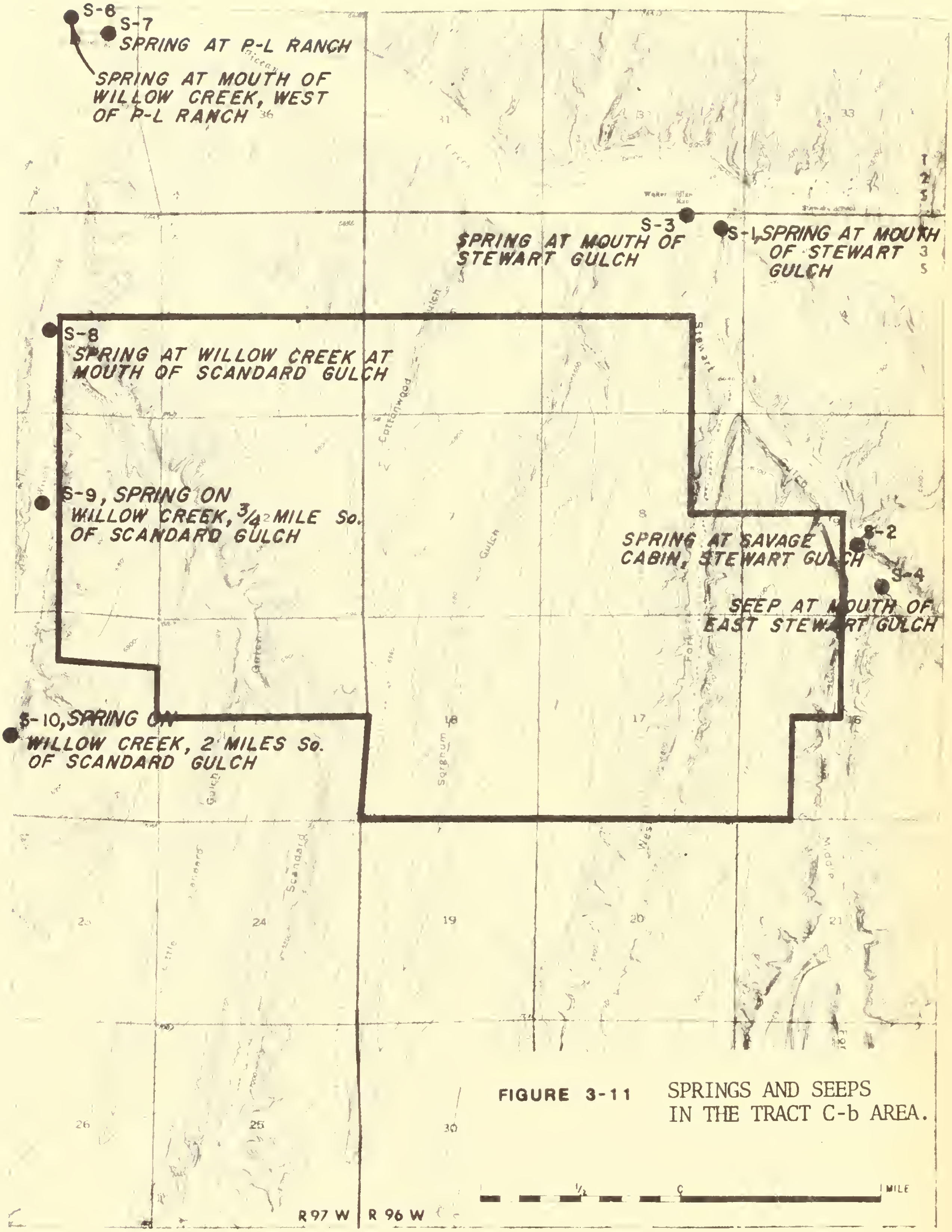


FIGURE 3-11 SPRINGS AND SEEPS IN THE TRACT C-b AREA.

Table 3-13 LOCATIONS OF SPRINGS AND SEEPS

Identification of Water Resources Division Springs

Designation	I.D.#	Location	Corresponding Identification in Figure 3-11
S-1 and S-1-A *	1081 1082	Lat 039°49'30" Long 108°11'07"	S1 and S3
CER-6**	1063	Lat 039°48'25" Long 108°10'34"	S2 and S4
W-1	1078	Lat 039°50'20" Long 108°14'35"	S6 and S7
W-2	1110	Lat 039°47'36" Long 108°14'59"	S9
W-3	1079	Lat 039°47'17" Long 108°15'03"	S10

* These springs are close by. Single flume measures the discharge from both the springs.

** This is a measuring site. Measure flow from two upstream springs.

3.1.3.5 Results and Discussion

3.1.3.5.1 Flow Records

Hydrographs for springs S-9 and S-10 are given in Figure 3-12 and for the state-designated station, CER-6, in Figure 3-13. Spring S-10 (State W-3) shows evidence of an annual cycle in flowrate. Three years of data are available, and an envelope enclosing all three lines in Figure 3-12 would clearly exhibit a gradual change from maximum flow in mid-winter to minimum flow in mid-summer.

The maximum and minimum points occur at essentially opposite times to the corresponding points for water levels in the alluvial wells (see Section 3.2.2). The time elapsing from the occurrence of a minimum to the next maximum is slightly less than the time from maximum to minimum. Alluvial water levels show the same relative behavior. Spring flows do not originate from the alluvial aquifers, but the recharge area should be subject to the same moisture cycles as the valley alluvium. The perennial character of the flow indicates a recharge area an appreciable distance from the spring, but the relatively large difference between maximum and minimum flow shows that the distance is not great enough to have damped out the seasonal effect.

Flows for spring, CER-6, (Figure 3-13) do not exhibit the same degree of cyclic behavior. S-10 flows out from the base of the valley wall, above the surface of the valley floor and therefore is probably unaffected in any way by the alluvium. S-9 and CER-6, on the other hand, rise through the valley floor and may be affected by water in the alluvium. Because of the 180 degree displacement of the alluvial water cycle, the result would be toward eliminating maximums and minimums in the flow record.

In an attempt to shed more light on the source of spring flow, a turbine flowmeter was installed at S-9 during September 1976. It was desired to see whether spring flow would correlate with barometric pressure (see Section 3.2.2 for barometric pressure effects in wells). A large barometric pressure effect would indicate a confined, or artesian aquifer as the source. The lack of a barometric effect could indicate a perched water table aquifer. Problems with plant debris in the stream resulted in only a two-week period of reliable flowmeter operation. Although the variations in barometric pressure during this period were small (Figure 3-14), there appears to be no correlation with the variations in spring flow.

HYDROGRAPH - SPRINGS W-2 & W-3 TRACT C-b STUDY AREA FOR YEARS 1974-1976

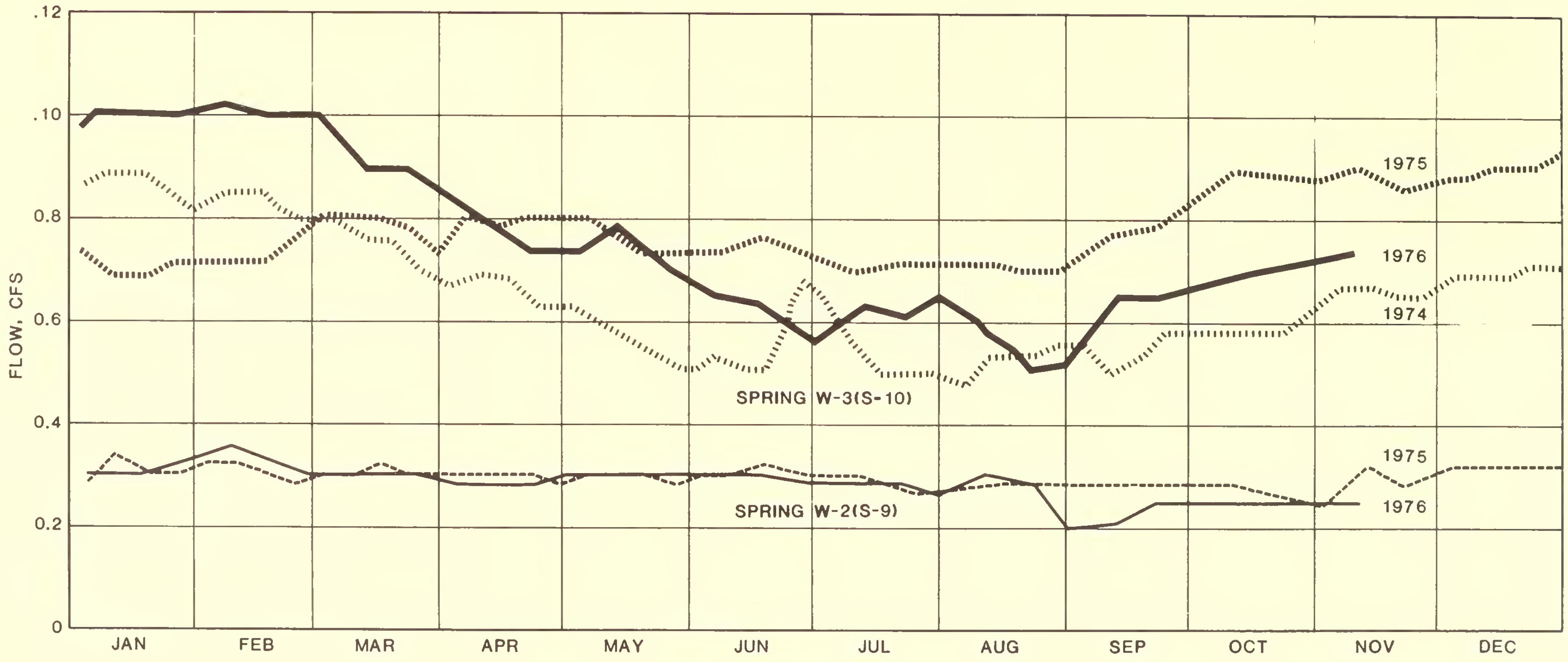


FIGURE 3-12

HYDROGRAPH - SPRING CER-6 TRACT C-b STUDY AREA FOR YEARS 1974 -1976

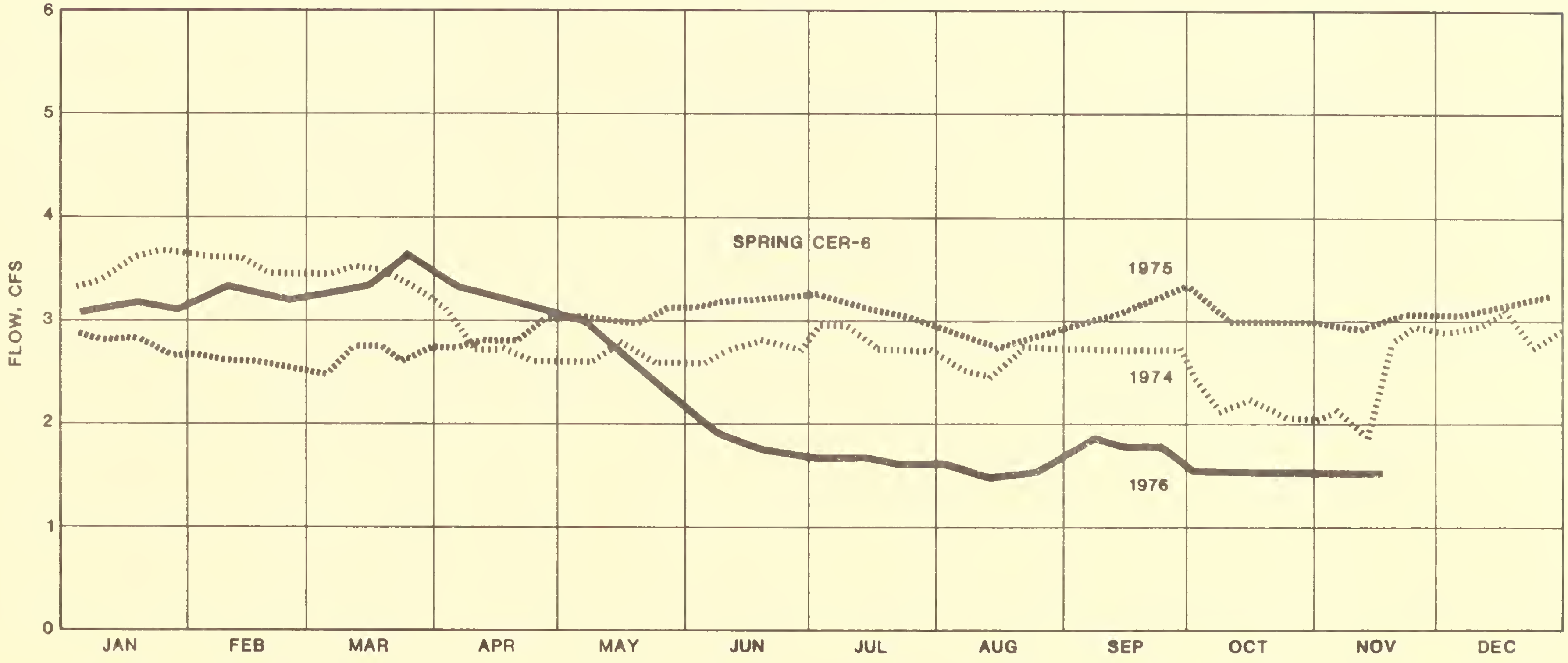


FIGURE 3-13

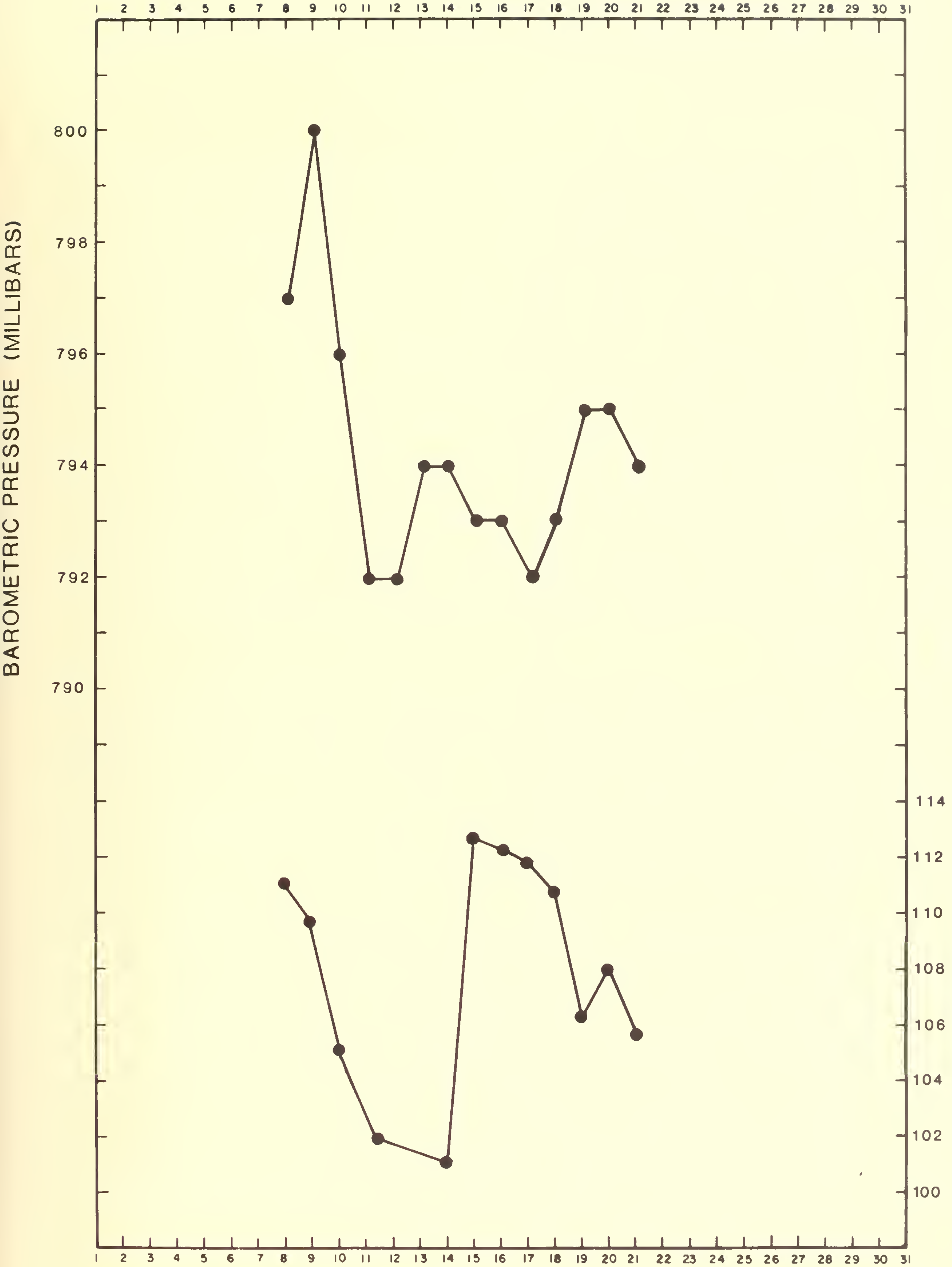


FIGURE 3-14 SPRING S-9 DAILY FLOW
SEPTEMBER, 1976

3.1.3.5.2 Water Quality

A total of 50 samples from the springs and seeps plotted in Figure 3-11 was collected and analyzed during the two-year baseline period. Complete data are listed in Tables A-4 through A-10 in the appendix. Mean, minimum, and maximum values for constituents of major importance are listed in Table 3-14. Interpretation of concentration data for those constituents present at levels well above the lower detection limits for the method of analysis is straightforward. For trace materials, however, the analytical results are often given only as "less than" the lower detection limit. In the appendix tables, ND (not detected) is used to mean that a specific element was tested for, but not detected at the lower limit of detection of the equipment. A horizontal line indicates that the analysis either was not performed or was judged to be faulty. A blank in the trace element analysis has the same meaning as ND. A value of "<" indicates that the constituent was detected but in insufficient quantities to derive a quantitative estimate. "ND" or blank values were not counted in computing the mean. This results in a mean value that is too high, but probably closer to the true value than the low result which would be obtained by counting "ND" values as zero. Values listed as "less than" were usually included in computing the mean. This too will obviously result in a too-high mean value, but was necessary in order to make use of the data available.

None of the mean values listed for important constituents have changed significantly from those reported at the end of the first year of the baseline program. With the minor exception of bicarbonate, all the final mean values fall within the 95 percent confidence interval for the mean calculated at the end of the first year. The final mean value for bicarbonate was 482 mg/1, compared to a mean of 520 and a 95 percent confidence interval of 488 to 547 for the first year's data. These results suggest that one year of data would have been adequate to define average chemical compositions.

Also listed in Table 3-14 are the proposed (October 1976) water quality standards for Colorado. The proposed standards are listed in seven different use categories. Table 3-14 lists the standard for agricultural (irrigation and stock) use and also lists the most restrictive value among all seven categories (based on cold water with over 400 mg/1 hardness). None of the agricultural standards are exceeded by the mean values. Maximum values have exceeded the agricultural standards for boron, chromium, copper, fluoride, manganese, and gross alpha radiation. The most restrictive standards usually apply to aquatic life. The most restrictive standards are exceeded by mean values for aluminum, copper, iron, mercury, phenols, and sulfate. Maximum values have been higher than the most restrictive standards for aluminum, chromium, copper, fluoride, iron, lead, manganese, mercury, phenols, alpha radiation, and sulfate, and possibly for arsenic, cyanide, selenium, and silver.

Table 3-14 WATER QUALITY - SPRINGS AND SEEPS

Constituent, mg/l	Mean	Minimum	Maximum	Agriculture Standard	"Most Restrictive" Standard
Conductance*	1300	840	1560		
pH*	8.2	7.3	8.5		
Total Dissolved Solids	925	547	1130		
Organic Carbon	5	2	10		
Aluminum	0.4	0.004	3	--	0.1
Ammonia	0.1	0.01	0.4	--	0.5
Arsenic	0.005	0.0005	<.05	0.1	0.01
Barium	0.04	0.01	0.1		
Beryllium	--	--	0.002	0.1	0.1
Bicarbonate	480	320	650		
Boron	0.4	0.001	1.6	0.75	
Bromine	0.02	0.004	0.08		
Cadmium	--	--	<.008	0.01	0.01
Calcium	83	28	160		
Carbonate	3	<.1	7		
Chloride	7	0.9	18	--	250
Chromium	--	--	0.1	0.1	0.05
Cobalt	0.007	<.001	0.05		
Copper	0.04	0.003	0.2	0.2	0.04
Cyanide	--	--	<0.1	0.2	0.005
Fluoride	0.45	0.1	2.1	2.0	1.4 - 2.0
Iron	<.4	0.01	7.8	--	0.3
Lead	0.02	0.001	0.05	0.1	0.05
Magnesium	78	28	100	--	125
Manganese	0.03	0.002	0.2	0.2	0.05
Mercury	0.0004	<.00003	0.002	0.01	0.00005
Molybdenum	0.03	<.005	0.2	0.5	0.5
Nickel	0.02	0.003	0.08	0.1	0.1
Nitrate	2.2	<.02	8.1	100	10
Phenol	0.015	--	0.037	--	0.001
Potassium	1.4	0.6	2.3		
Radiation, Alpha*	6	0	20	15	15
Radiation, Beta*	4	0	30	50	50
Rubidium	0.01	0.001	0.05		
Scandium	0.005	<.001	0.02		
Selenium	--	--	<.04	0.05	0.01
Silica	16	12	21		
Silver	--	--	<.001	--	0.00025
Sodium	130	68	240		
Strontium	2.0	0.6	5		
Sulfate	360	200	440	--	250
Thallium	--	--	--	--	0.015
Titanium	0.2	0.02	0.6		
Uranium	--	--	--	--	0.075
Vanadium	0.005	<.001	0.02		
Zinc	0.08	0.01	0.4	2.0	0.6

*not mg/l

The above results indicate the relatively poor quality of the spring waters. Some minor differences can be seen between the springs along Willow Creek and those along Stewart Gulch. For instance the mean fluoride content of the Willow Creek springs as a group is 0.28 ± .05 mg/1 while that for the Stewart Gulch springs is 0.57 ± .09. In general, however, the compositions are rather uniform from spring to spring, suggesting that all are supplied by the same aquifer system. Increases in dissolved solids occur in the direction of surface stream flows. Referring to Figure 3-15 it can be seen that mean values for conductivity, total dissolved solids, sodium, and sulfate, for example, all tend to increase with distance downstream in a drainage. Going downstream, the conductivity of the springs along Willow Creek increases from 1215 at S-10, to 1279 at S-9, to 1322 at S-8, to 1342 at S-7, to 1372 at S-6. A similar pattern is present along Stewart Gulch. This suggests that the springs are part of the overall basin ground water system, which flows north to Piceance Creek, gradually increasing in dissolved solids content as it flows.

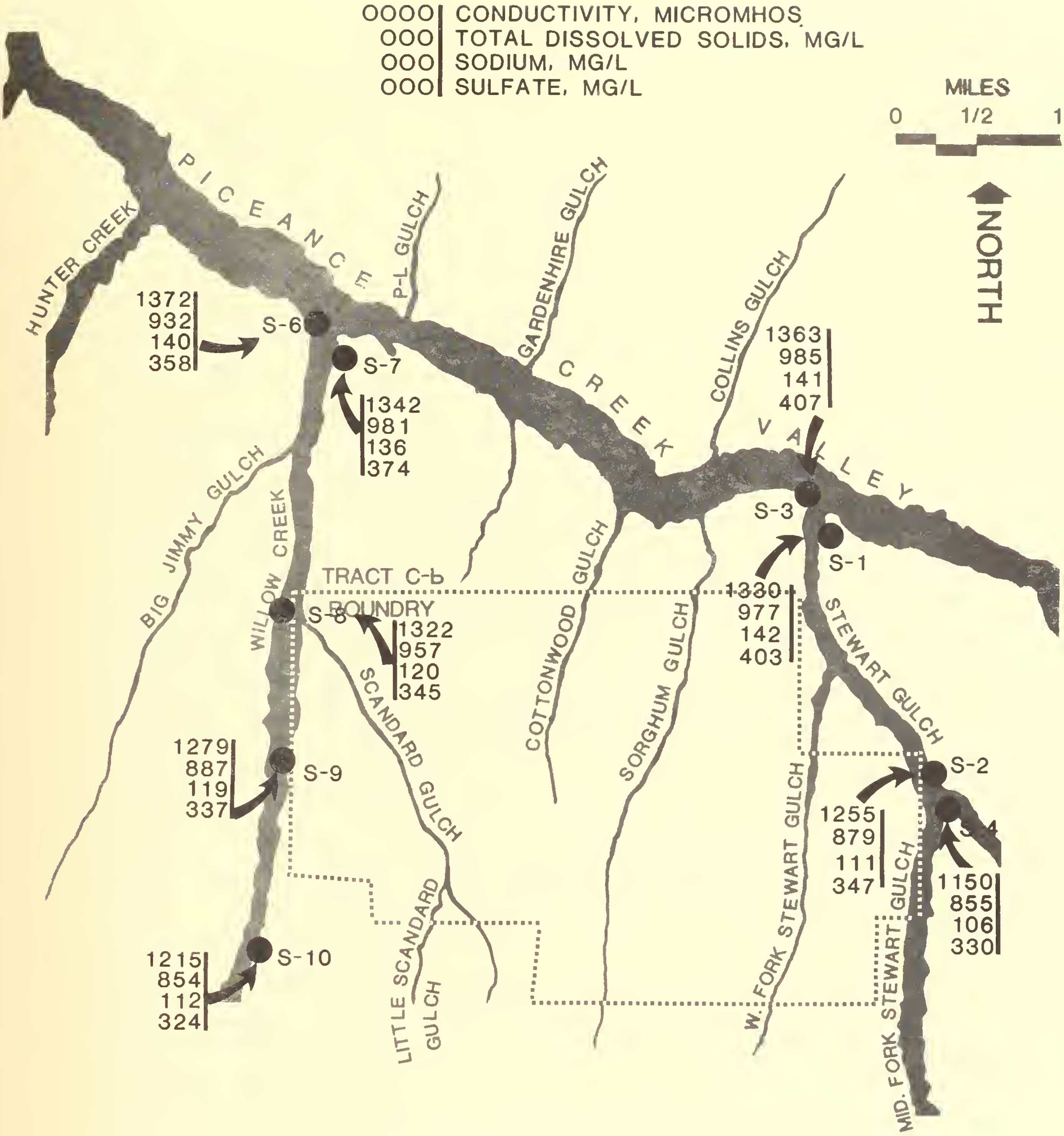
Samples from four springs were submitted for radiocarbon age analysis. The results are listed in Table 3-15.

Table 3-15 RADIOCARBON AGE ANALYSIS OF SPRING WATERS

Spring	Age, Years
S-4	3560 ±230
S-5	5680 ±165
S-7	2960 ±195
S-8	2800 ±215

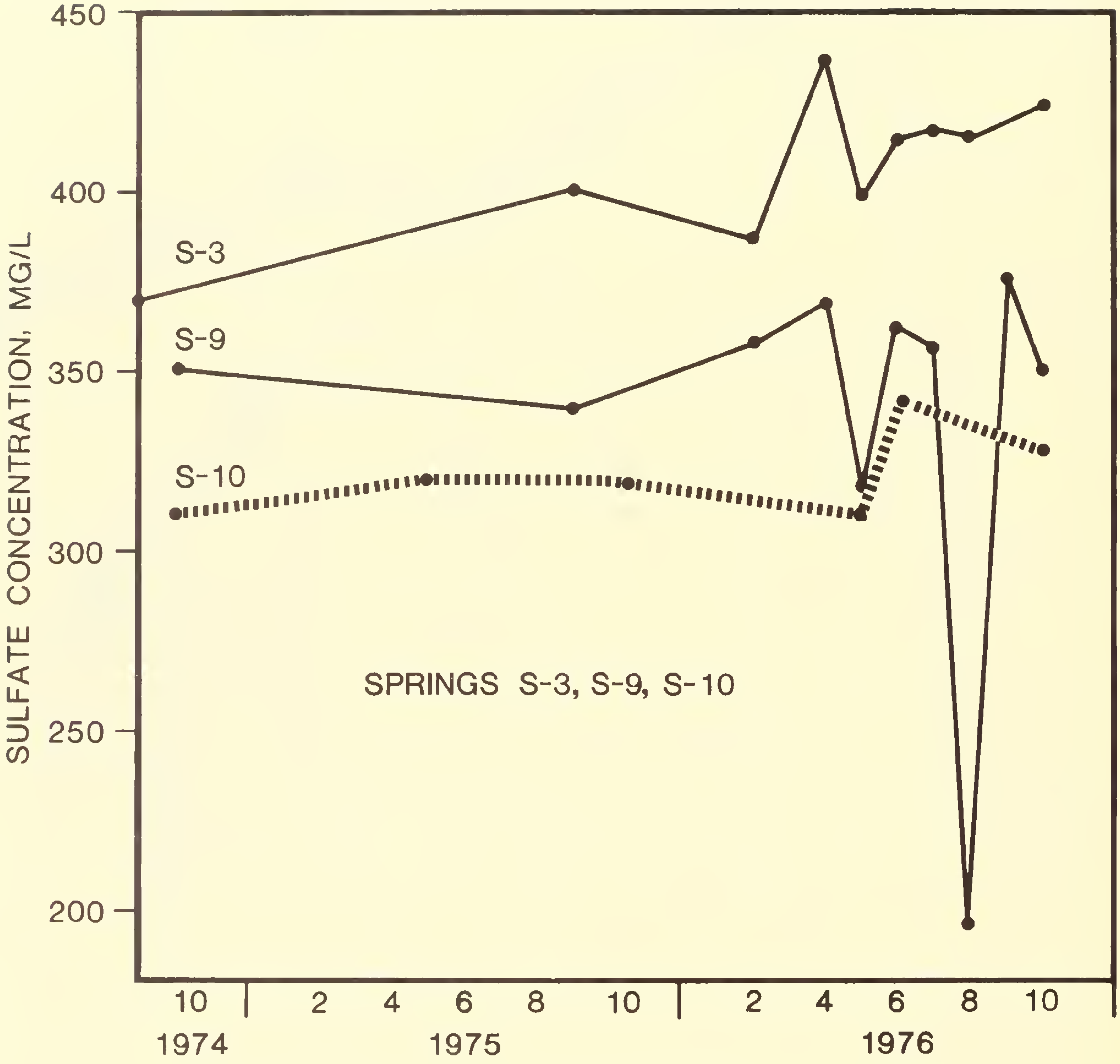
The use of radiocarbon dating for determining the "age" of ground water, i.e., length of time since infiltrating from the surface, is fraught with complex difficulties. There is no way of determining for certain how much of the carbon in the water was derived from the soil horizon during infiltration (and having an age equal to that of the precipitation) and how much was obtained from dissolution of minerals far underground, which would contain carbon of geological age. For this reason no conclusions concerning the spring sources have been drawn based on the radiocarbon data.

The considerable variability of the chemical data overshadow any cyclic or long-term patterns which may be present. Data from springs S-3, S-9, and S-10 (those which have been sampled the greatest number of times) for sulfate and sodium concentrations are given in Figures 3-16 and 3-17 respectively. No correspondence with the cyclic flow pattern for spring S-10 in Figure 3-12 can be seen. Although certain month-to-month changes appear to show some correspondence between the three springs, this may be related to common variations in sample handling and analysis rather than actual changes in the water.



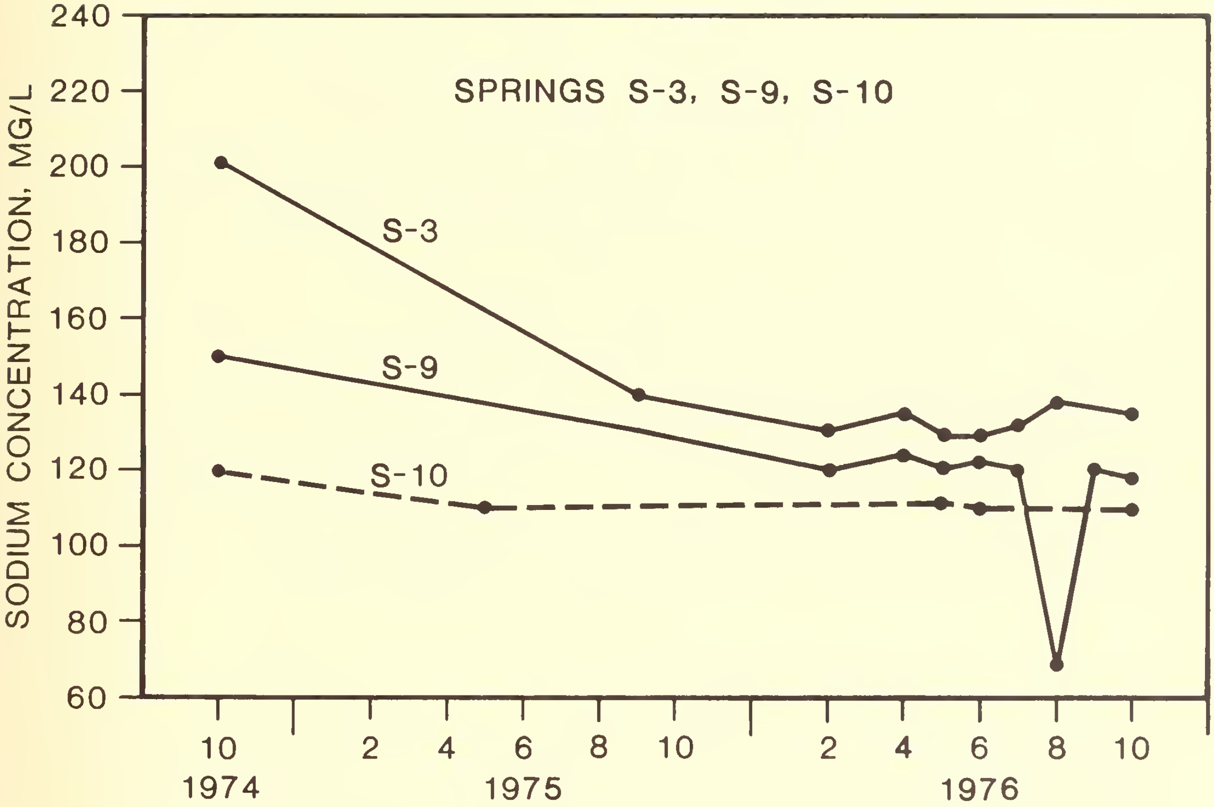
VARIATION OF WATER QUALITY

FIGURE 3-15 IN SPRINGS AND SEEPS



SULFATE CONCENTRATIONS IN SPRINGS

FIGURE 3-16



SODIUM CONCENTRATIONS IN SPRINGS

FIGURE 3-17

3.1.4 Precipitation on Tract C-b

3.1.4.1 Rationale for Measurement

The amount of precipitation an area receives is important in surface hydrology and to air quality. It is important in a hydrologic sense as input to the ground water and surface water systems. It is important in air quality studies because precipitation is a natural removal process for atmospheric pollutants. This removal process can effect soil chemistry and water quality.

During the past ten years increasing interest has been shown by investigators in the phenomena of precipitation washout and rainout. Washout is the absorption and capture of particles by raindrops; rainout is the absorption of the particles within a cloud and subsequent precipitation. These mechanisms are classed as precipitation scavenging and are two of several mechanisms for removing atmospheric gases and particulate matter.

A great deal of this literature has focused on acid rains and thus the scope of the investigations are devoted geographically to industrial areas and to the effects of the acid rain on man's structures. As the breadth of the investigation widens, it is becoming increasingly clear that washout and rainout can contribute significant amounts of chemical constituents to the natural environment and can have a significant effect, deleterious or beneficial, on that environment.

The quantity of precipitation varies geographically. It is a function of topography, continentality, season, latitude, and atmospheric parameters on a large scale, and such parameters as topography, elevation, and vegetation on a microscale. Because of the local variations in quantity and the effects of precipitation as a driving variable on the various systems, precipitation gauges were established throughout the Tract in the hydrology, air quality, and microbiology programs. The regional and local climatology of the Piceance Creek basin are discussed in Volume I of this series, meteorology and air quality are discussed in Volume III.

3.1.4.2 Objectives

The objectives of this task were to collect information on the quantity and type of precipitation and to gather precipitation samples on the Tract and have them analyzed for major constituents. Samples were to come from one station upwind of the Tract and one station downwind of the Tract. The analyses would provide data for estimates on the effect of precipitation scavenging on the surface waters of the C-b Tract.

3.1.4.3 Experimental Design

A precipitation gauge network was established (Figure 3-18). The air quality program placed automatic tipping bucket snow-rain gauges at each air quality trailer. The recorders were powered by A.C. current from the air quality trailers. Each gauge was electrically heated and insulated. The microbiologic program established a network of microclimate stations each equipped with a tipping bucket gauge. The remote recording instrumentation recorded cumulative precipitation every 20 minutes. Stations 1 and 4 were powered by 12-volt batteries and the precipitation gauges heated with propane. Stations 2 and 3 were A.C. powered and the precipitation gauges were electrically heated. Cumulative precipitation storage gauges were placed at four water gauging stations in the Tract study area. An additional weighing bucket and digital recording precipitation gauge is located south of the Tract on the Roan Plateau. The gauges at Middle Fork Stewart Gulch and Scandard Gulch are standard eight-inch cumulative gauges. Those at Willow Creek and Stewart Gulch are small forestry gauges. Each gauge is read every two weeks.

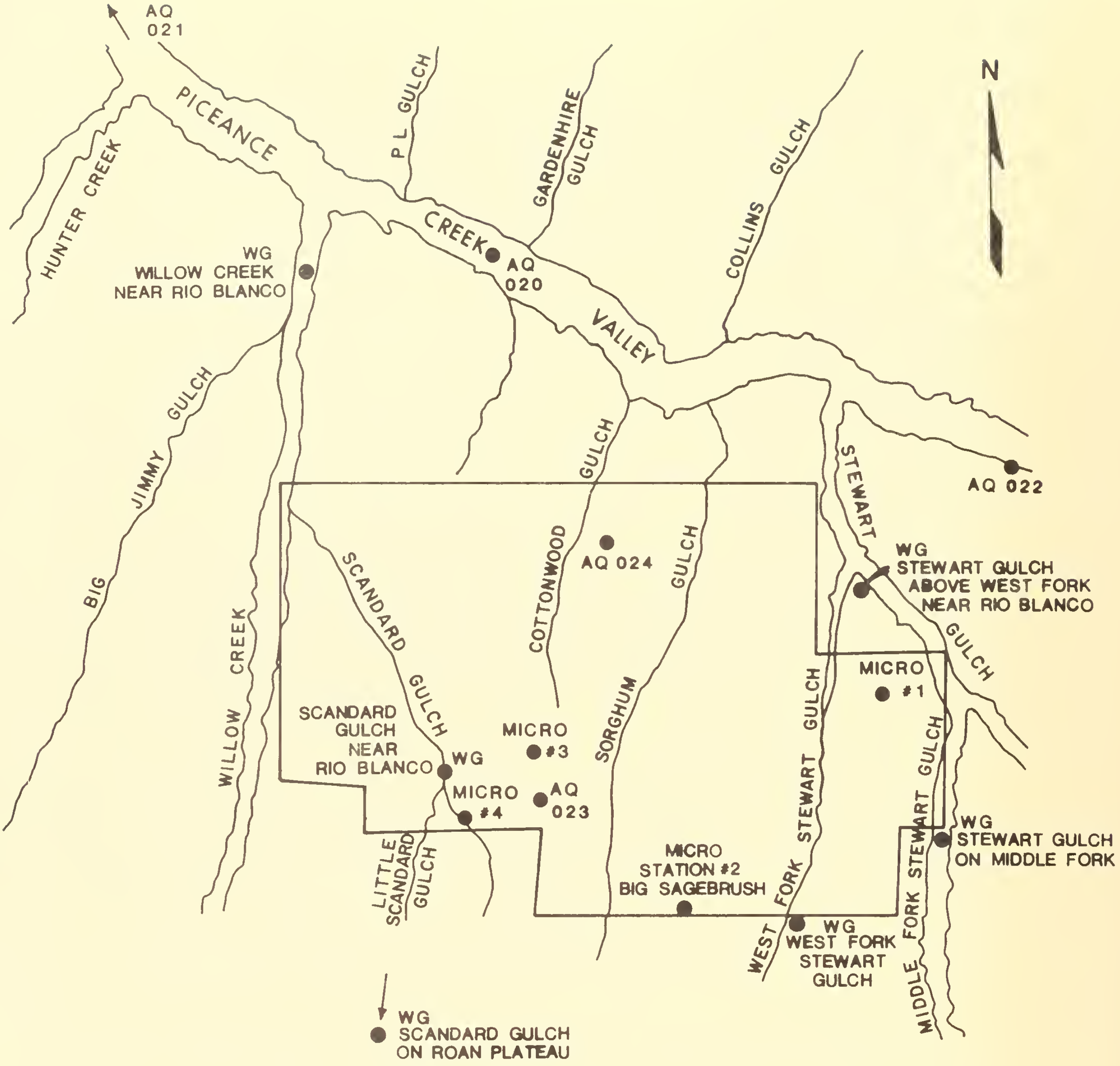
Samples were obtained of snow and rainfall at two locations on the Tract study area. The locations for the sampling gauges were the drill pads for Wells Cb-2 and SG-18A. Cb-2 is located at the northern edge of the Tract on the divide between Cottonwood and Sorghum Gulch and is the downwind station. SG-18A is located more than one and one-half miles south of the Tract on the divide at the head of Sorghum Gulch and is the upwind station. At an elevation of 7380 feet, SG-18A is about 650 feet higher than Cb-2.

One sample of snow and two rain samples, one in June and one in July, were taken at each station. Samples were taken to the laboratory of The Oil Shale Company for analysis using the same methodology as on the ground water samples.

3.1.4.4 Results and Discussion

3.1.4.4.1 Precipitation Quantity

As discussed in Volume I, the general climate of the Piceance Creek basin is regulated by the mountains to the west which serve to desiccate easterly moving air masses and by such atmospheric parameters as the regional high pressure cell, or long wave ridges in the upper atmosphere, which dominate northwest Colorado much of the year. The subsiding air heats as it approaches the surface (adiabatic compression) thereby increasing its water holding capacity and serves to maintain low humidity and dry conditions.



AQ = AIR QUALITY STATION

WG = WATER GAUGING STATION

MICRO = MICRO-ENVIRONMENT STATION

FIGURE 3-18 LOCATION OF PRECIPITATION GAUGES ON OR NEAR TRACT C-b

The increase in elevation over areas to the west, offered by the plateau upon which it is found, and the Rocky Mountains to the east, aid in lifting air masses sufficiently to increase precipitation eastward across the Piceance Creek basin. Elevation and topography have such a marked effect on local climates that it is difficult to project information obtained over more than a small radius from a recording station. Average precipitation data and recorded values for the baseline period for selected Weather Bureau stations are shown in Tables 3-16 and 3-17. As can be seen, annual average precipitation values vary 12 inches between Meeker at 6347 feet elevation and Marvin Ranch at 7800 feet elevation; the precipitation at Little Hills, 6140 feet elevation, is two inches less than that at Meeker. In the vicinity of the Tract, the effect of elevation on precipitation can be seen between the stations on the Tract (Tables 3-18 and 3-19) and the amount of precipitation recorded at USGS gauge at Scandard Gulch on Roan Plateau some 2000 feet higher than the Tract (Table 3-20).

The effect of elevation can be further dramatized by comparing long term precipitation at Little Hills and Meeker with stations to the south along the Colorado River, e.g., Rifle and Grand Junction. The Colorado River stations are over 1000 feet lower in elevation than the C-b Tract and yearly precipitation is as much as 6.4 inches less than Meeker's yearly average. It is obvious that climatic comparisons with Grand Junction or even Rifle would lead to erroneous conclusions.

One problem that can be seen in Table 3-20 (showing precipitation by season for various stations) is the significant difference in recorded precipitation at the air quality trailers. These stations recorded a total average precipitation of only 7.03 inches over the baseline period. This is significantly less than any other gauge or group of gauges reported. A region receiving only 7.00 inches of precipitation yearly would be classified as arid. The largest difference is in the winter months. Part of the discrepancy may be because of instrumentation problems during the start-up period in November and December 1974. Another explanation is that the gauge at the trailer is off when power to the trailer is off. Therefore each time the power to the trailer is interrupted the precipitation recorder is off. The most likely time for power interruption is during a severe storm. Time series plots for precipitation at the air quality trailers are shown in Figure 3-2.

The gauges at the microenvironmental stations are all affected by vegetation canopy. Gauge Number 2 in the Big Sagebrush vegetation-type was the least affected of the four. Monthly data from these stations are shown in Table 3-21.

Table 3-16 RECORDED PRECIPITATION (INCHES) OVER THE BASELINE PERIOD AT SELECTED WEATHER BUREAU STATIONS

	LITTLE HILLS 6140'			MARVINE RANCH 7800'			MEEKER #2 6347		
MONTH	1974 PPT	1975 PPT	1976 PPT	1974 PPT	1975 PPT	1976 PPT	1974 PPT	1975 PPT	1976 PPT
JAN		.80	.47		3.05	.41		.62	.47
FEB		.69	.74		1.59	1.17		.34	.74
MAR		1.60	1.65		3.00	1.92		1.24	1.37
APR		1.58	1.20		2.77	1.45		1.76	1.25
MAY		2.33	1.96		2.64	1.56		1.64	1.44
JUNE		1.75	1.60		1.24			1.72	1.43
JULY		3.00	1.08		2.49			2.04	2.03
AUG	.34	.36	1.79	.95	.72	1.86	.47	.44	1.18
SEPT	.32	.72		1.15	.57		.49	.48	
OCT	.66	1.55		1.53	1.20		.76	1.30	
NOV	.33	.75		.79	2.64		.58	.47	
DEC	.84	.78		3.98	.67		1.32	.67	

Table 3-17

	RIFLE 5400				GRAND JUNCTION		
MONTH	1974	1975	1976	AVE.	1974	1975	1976
JAN		.84	.50	.92		.84	.52
FEB		1.11	1.81	.76		1.11	1.81
MAR		1.46	1.81	.87		1.46	1.45
APR		.80	.89	.93		.80	.89
MAY		1.08	1.58	.81		1.08	1.58
JUNE		1.02		.92		1.02	1.10
JULY		.42		.85		.42	.29
AUG	.89	.10	1.13	1.25		.10	1.13
SEPT	.46	.25		.92		.25	1.48
OCT	.87	.61		1.24		.61	.22
NOV	.65	.61		.85	.65	.61	
DEC	1.26	.94		.92	1.26	.94	

Table 3-18 RECORDED PRECIPITATION (INCHES) OVER THE BASELINE PERIOD AT WATER GAUGING STATIONS

	STEWART GULCH AT WEST FORK			MIDDLE FORK STEWART GULCH			WILLOW CREEK		
	1974	1975	1976	1974	1975	1976	1974	1975	1976
JAN		-	-		-	-		-	-
FEB		1.00	-		.50	1.60		-	-
MAR		1.08	-		.48	1.75		-	-
APR		0.28	.78*		1.00	.70		-	.56*
MAY		-	1.60		1.01	1.20		-	.91*
JUN		-	.79		2.04	.79		-	1.14
JUL		.65*	1.67		.93	1.15		.87*	1.61
AUG		1.13	.89		.12	.05		.65	.44
SEPT		.48	1.10		.26	.97		.43	-
OCT		1.00	.20		1.10	.21*		.90	.18*
NOV	-	-	-	-	1.10	.04	-	-	-
DEC	-	-	-	-	.80	.00	-	-	-

	SCANDARD GULCH NEAR RIO BLANCO			SCANDARD GULCH ON ROAN PLATEAU		
	1974	1975	1976	1974	1975	1976
JAN		-	-		2.26	.58
FEB		.50	1.70		1.58	3.43
MAR		.60	1.70		2.67	2.29
APR		.65	.65		2.05	1.32*
MAY		.11	1.37		.95*	-
JUN		.00*	.63		.09*	1.59*
JUL		.50	.95		1.00	1.82
AUG		.20	Tr.		.17	.66
SEPT		.38*	.80		.40	1.69
OCT		.65	.05*		1.91	.58
NOV		.70	.00	1.51	1.95	.31
DEC		.79	.00	1.33	1.58	.33

Monthly totals are approximations since gauges are not read at the end of the month but approximately at 14 day intervals.

*Part of the record missing.

Table 3-19 PRECIPITATION RECORDED AT AIR QUALITY TRAILERS IN TRACT C-b STUDY AREA OVER BASELINE

	Trailer 020			Trailer 021			Trailer 022			Trailer 023			Trailer 024				
	1974	1975	1976	1974	1975	1976	1974	1975	1976	1974	1975	1976	1974	1975	1976	Ave.	
JAN		1.16	.04		.78	.01		.52	.07		.62	.05		.31	.08	.36	
FEB		---	.70		.04	.27		.25	1.53		.17	.64		.26	.84	.52	2.15
MAR		.85	.82		.51	.08		1.72	.52		.78	.62		.82	.37	.71	
APR		.85	.60		.59	.11		.73	.64		.74	.49		.89	.65	.63	2.35
MAY		1.08	.67		1.13	.88		1.29	.25		1.44	.57		1.79	1.02	1.01	
JUNE		.32	.93		.73	.59		.24	.56		.44	.98		.07	---	.54	
JULY		.70	1.08		.48	1.67		1.61	.04		.96	1.10		---	---	.96	2.03
AUG		.67	.36		---	.09		1.25	---		.13	.67		---	---	.53	
SEPT		.05	1.05		.30	.34		.24	---		.27	1.12		.20	---	.50	.50
OCT		1.00	.18		.66	.20		.41	---		.34	.19		1.07	---	.53	
NOV	---	.51		---	.23	---	---	.83		---	.34		---	.46		.47	
DEC	---	.43		---	.32	---	.02	.48		---	.29		.01	.31		.27	
		7.62			5.77			9.57			6.52			6.27			

- No Data

Table 3-20

PRECIPITATION BY SEASONS (INCHES),
SELECTED STATIONS, PICEANCE CREEK BASIN

SEASON	1941-1970 AVERAGE^2	LITTLE HILLS 11 YR MEAN	LITTLE HILLS 75	MEEKER 11 YR MEAN	MEEKER 75	WATER GAUGES ON TRACT C-b AVE. 75 & 76	SCANDARD GULCH ON ROAN PLATEAU 75	SCANDARD GULCH ON ROAN PLATEAU 76	AIR TRAILER AVERAGE 75 & 76^3	MICROENVIRONMENTAL STATION AVERAGE 75 & 76
W	<4	4.29	4.05	5.42	3.34	6.66	9.35	9.55	2.33	4.93
Sp	<2	2.93	3.91	2.79	3.40	1.74	3.00	2.55	1.64	1.93
S	<3	4.06	5.11	4.41	4.20	2.42	1.26^3	2.75^3	2.03	2.33
F	2	2.45	2.27	2.74	1.78	1.58	2.31	2.15	1.03	.47
	TOTAL	13.73	15.34	15.36	12.72	12.40	15.92	17.00	7.03	9.66

1 Winter is November through March; Spring = April, May; Summer = June, July, August; Fall = September, October

2 See discussion in Volume I (Source, Bradley 1976)

3 Data missing

Table 3-21 PRECIPITATION (INCHES) RECORDED AT MICROENVIRONMENTAL STATIONS, TRACT C-b

MICRO STATION #1
PINYON-JUNIPER WOODLAND

	1974	1975	1976
JAN		.80	1.18
FEB		2.24	.94
MAR		.26	.32
APR		1.34	.67
MAY		1.36	.92
JUN		2.04	1.00
JUL		1.28	.22
AUG		.26	.36
SEPT		.30	.20
OCT		.87	.17
NOV		.55	
DEC	.68	.88	

MICRO STATION #2
BIG SAGEBRUSH

	1974	1975	1976
JAN		1.40	1.48
FEB		2.00	1.24
MAR		0.32	1.36
APR		0.26	1.56
MAY		1.05	1.00
JUN		1.26	.65
JUL		1.40	.65
AUG		.16	.52
SEPT		.47	.02
OCT		.18	.26
NOV		.52	.04
DEC	1.08	.46	-

MICRO STATION #3
CHAINED PINYON-JUNIPER

	1974	1975	1976
JAN		1.68	.88
FEB		1.80	.56
MAR		.74	1.32
APR		.26	.61
MAY		.73	.58
JUN		1.31	.72
JUL		1.82	1.12
AUG		.17	.71
SEPT		.19	.29
OCT		.17	.19
NOV		.28	
DEC	.68	.51	

MICRO STATION #4
BOTTOMLAND SAGEBRUSH

	1974	1975	1976
JAN		.84	.92
FEB		1.28	.99
MAR		.26	1.28
APR		.52	1.42
MAY		1.08	.80
JUN		1.85	.75
JUL		1.77	.16
AUG		.41	.59
SEPT		.14	.32
OCT		.20	.18
NOV		.58	
DEC	.48	.61	

As discussed in Volume I the long-term monthly averages show a small deviation from the monthly mean of the long-term yearly average, i.e., there is little variation in average monthly precipitation. However, precipitation for any given year is not equally distributed from month to month and the standard deviation from the mean is large. This indicates that precipitation may be compared to the average by the year or by the season but comparisons cannot be made on a monthly basis. Using this criterion, a comparison with other stations shows that in 1975, there was a wet spring and an early wet summer. This pattern shows up at Scandard Gulch and on the Middle Fork Stewart Gulch but not at Stewart Gulch near Rio Blanco. There is not enough data at West Fork Stewart Gulch and at Willow Creek for comparison. This pattern is also shown at the microenvironmental stations.

Further comparison shows a dry, late summer. This pattern is indicated by the precipitation recorders at all water gauging stations except at West Fork Stewart Gulch where 1.13 inches were recorded in August and at all microenvironmental stations. The precipitation recording station at air quality trailer 022 recorded 1.61 inches of precipitation in July and 1.25 inches in August. This trailer is located about two miles northeast of the West Fork Stewart Gulch water gauging station. These data indicate that the eastern portion of the Tract might have received more precipitation than the balance of the Tract during the late summer of 1975. However, if such is the case, gauges on Middle Fork of Stewart Gulch and Stewart Gulch near Rio Blanco should have recorded more precipitation.

Over the baseline a general comparison to averages for the year 1941 through 1970 (Bradley 1976) would indicate that the Tract received about average precipitation during the winters of 1975 and 1976. The springs were average or drier than average over most of the Tract but wetter than average at Little Hills, Meeker, and Scandard Gulch (and Middle Fork Stewart Gulch as discussed above). The summers were drier at all stations except Little Hills and Meeker (and West Fork Stewart Gulch) and falls were about average at all stations, except at the microenvironmental stations. Interception by the canopy is a factor in trying to correlate precipitation at these stations with that at the water gauging stations.

The gauges that give the greatest amount of precipitation for the Tract are the precipitation gauges at the water gauging stations. An average at these stations for the baseline indicates precipitation is equal to or greater than 12.4 inches per year. The average is "equal to or greater than" because data was not gathered at some intervals through the baseline and these gauges were affected to a certain degree by evaporation. It is interesting to note that a Thiessen approximation for the Tract, using 1975 data from Rangely, Little Hills, Meeker, Rifle, Grand Valley, and Altenbern gives a figure of 12.95 inches of precipitation for the Tract in 1975.

3.1.4.4.2 Precipitation Quality

Although precipitation gauges were installed in the fall of 1974, it was not until the 1976 water year that precipitation was analyzed for major constituents. Results of these analyses are shown in Table 3-22. The two columns on the right of the table show means for values obtained on the Tract and means from inland sampling stations sampled by Junge and Werby (1958). The average for the pH is taken from Dochinger and Seliga (1975).

Mean values for sodium, potassium, calcium, and magnesium from the samples taken on the Tract approximate those published by Junge and Werby. Chloride is reported as <1. Assuming that the chloride-sodium ratio of 1.88 for sea water is applicable to the Tract then the chloride content of precipitation should be about 0.62 mg/1. However Junge and Werby found that the Cl/Na ratio inland was always less than that of sea water and inland averages show a Cl/Na ratio of .52. Using this value would give a chloride content of approximately .17 for the Tract which is more in line with the average supported by Junge and Werby. In this light the chloride value of the snow at Cb-2 appears excessive even though Junge and Werby suggest that higher Cl/Na values will be observed in the winter when continental areas are related to a more maritime climate and a period of increased westerly circulation.

One data set is not enough information to make any interpretative conclusions for the Cl/Na ratio of snow. The six analyses shown in Table 3-22 are insufficient for determination of causal relationships. It is interesting however, that the rainfall even in February, discussed at length in the section on surface water quality, apparently contributed Kjeldahl nitrogen to the surface water in amounts sufficient to create a maximum reading for that station. No explanation is offered for the high Kjeldahl nitrogen readings.

3.1.4.5 Summary

The climate of the Piceance Creek basin and hence the Tract can be classified as semi-arid. The greatest amount of precipitation is received in the winter as snow. The spring melt of the accumulated snow on the higher elevations contributes to the April peak in streamflow and also contributes to the recharge of ground water. Springs and falls are drier than the summers, when convective storms bring about 20-25 percent of the total yearly precipitation. The Thiessen method of approximating a precipitation record is about equal to the average precipitation recorded at the four water gauging stations bordering the Tract. A total of 12.5 inches is estimated for the yearly precipitation at Tract C-b over the baseline period.

Table 3-22

CHEMICAL ANALYSIS OF PRECIPITATION - C-b TRACT (mg/l)

	SG-18A			Cb-2				
	snow	June	July	snow	June	July	Mean Of All C-b Values	*
Sodium	0.8	0.3	0.1	0.3	0.3	0.2	0.33	0.42
Potassium	0.1	0.2	0.1	0.2	0.2	0.2	0.2	0.17
Calcium	1.0	1.6	1.1	1.0	1.7	1.3	1.3	1.41
Magnesium	0.4	0.3	0.3	0.4	0.3	0.2	0.3	
Lithium	<.5	<.5	<.5	<.5	<.5	<.5		
Strontium	<.1	<.1	<.1	<.1	<.1	<.1		
Iron	<.1	<.1	<.1	0.2	<.1	<.1		
Manganese	<.1	<.1	<.1	<.1	<.1	<.1		
Arsenic	.003	0.5	<.5	≤.002	0.5	0.5		
Mercury	<.03	<.03	<.03	0.001	0.03	<.03		
Sulfate	<4	<4	<4	<4	<4	<4		2.14
Carbonate	<1	ND	ND	<1	ND	ND		
Bicarbonate	<5	9	8	<5	9	9	<8	
Chloride	<1	<1	<1	1.2	<1	<1		0.22
Fluoride	<.1	<.1	<.1	<.1	<.1	<.1		
Boron	<.1	ND	ND	<.1	ND	ND		
pH	6.7	6.6	6.7	6.6	6.8	6.7	6.7	5.7**
TDS	2.3	7	6	2.1	7	6		
Kjeldahl N	1.3	1.5	0.8	1.8	1.2	1.2		

ND - Not detected

* Average for inland sampling stations in United States for 1 year. Data from Junge & Werby (1958) as reported by Whitehead & Feth (1964).

** Ambient figure from Duchinger & Seliga (1975)

The efficiency of precipitation scavenging is still being studied by many investigators. The effects of atmospheric removal mechanisms on the natural environment are becoming better defined with each new investigation. Results of the analyses for chemical constituents on Tract C-b show some averages within the value range of those suggested by more detailed studies. More data are needed to suggest a causal relationship between precipitation and surface water chemistry.

3.1.5 Surface Water Quality

3.1.5.1 Rationale for Measurement

Analysis of surface water samples over a two year period provides data for establishing a background or baseline against which future analyses can be compared. The analysis serves to establish parameters, such as water type and principal ions, that identify the water and establish its character in a regional and temporal sense.

Regionally, surface water chemistry depends in a large part on the lithology of the drainage basin. Surface lithology and weathering processes have great influence if the predominant contribution to stream flow comes from runoff. If ground water is the predominant source of stream flow, stratigraphy, structure, and the lithology affect ground water flow and chemistry and hence the surface water chemistry. Thus a knowledge of the chemistry of surface water contributes to the knowledge of surface and subsurface geology.

Other contributors to the chemistry of surface water are the atmosphere, agriculture, municipalities, and industry. The atmospheric contribution to surface water chemistry through rainwash is ubiquitous. The effect of the contribution depends on local meteorology and regional climatology. The most important elements of both would be local and prevailing regional wind conditions and the amount and timing of precipitation.

Municipalities and industries can affect the chemistry of surface water through their discharges, wastes, and consumptive uses. Also, the materials and chemicals put into the atmosphere are washed out or fall out to affect surface materials and water. Agriculture affects surface water chemistry through runoff over croplands treated with insecticides, herbicides, and fertilizers. Runoff over feed lots or pastures where livestock have grazed can contribute large amounts of nitrogen and bacteria to surface water supplies.

Because the Lessee of the C-b Oil Shale Tract must comply with any local, state, or federal water pollution regulations and water quality standards, it is necessary to ascertain if natural conditions alone exceed those standards.

3.1.5.2 Objectives

The objective of measuring the various parameters is to establish a two-year baseline for comparison against water quality standards and against future analyses and to ascertain variations in quality both temporally and regionally. Furthermore, water analyses aid in the understanding of the geochemical and hydrologic relationships in the region of the Tract and in evaluating the influence of man's activities.

3.1.5.3 Experimental Design

Of first importance in selecting a water quality sampling site is the extent to which the site would provide data of benefit to the overall program. Locating a water quality station at a stream-gauging station makes it possible to provide flow data essential in computing the dissolved load and in evaluating patterns.

Surface water stations were established on Piceance Creek above and below the Tract and at least one station was established on each tributary within or bordering the Tract. At each station records, continuous where possible, were collected on flow, water temperature, pH, conductance, and sediment. An analysis for selected inorganics and organics was made on a periodic basis. Precipitation stations were located and analyses of precipitation samples were made to determine the character of precipitation and the impact of precipitation on water quality.

Initially samples of streams were obtained and analyzed every two weeks. When variability is small, frequency can be reduced to seasonal analyses and still achieve the desired accuracy. Some measurement can be omitted entirely except for periodic checks to see if values remain negligible. After the first year's baseline data were gathered and analyzed, sampling was changed to monthly, except for trace elements and insecticides which were analyzed quarterly (Table 3-23). Data on some major inorganic constituents show that the ionic concentrations are generally related to flow rate and deterministically related to the conductivity. Thus, once estimates of ionic proportions are made within acceptable limits, inorganic water quality can be estimated from conductivity and flow, both of which are measured continuously.

3.1.5.4 Methodology

Depth-integrating samplers are used to collect water samples for analyses of nonvolatile constituents and those unaffected by aeration. A depth-integrating sampler holds the sample bottle in such a manner that when the device is lowered in the stream at a

TABLE 3-23 SURFACE WATER QUALITY ANALYTICAL PROGRAM REQUIREMENTS

	Semi-Monthly	Quarterly	Continuous	Continuous When Possible
1. Ammonia	x			
2. Aromatics, Polycyclic		x(M)		
3. Arsenic	x			
4. Barium	x			
5. Bicarbonate	x			
6. Boron	x			
7. Cadmium	x			
8. Calcium	x			
9. Carbonate	x			
10. Chloride	x			
11. Chromium	x			
12. COD		x(M)		
13. Coliform, Total & Fecal		x(M)		
14. Color	x			
15. Conductivity, Specific			x(M)	x(0)
16. Copper	x			
17. Cyanide	x			
18. Dissolved Oxygen	x		x(M)	
19. Fluoride	x			
20. Gross Alpha*		x(M)		
21. Gross Beta*		x(M)		
22. Iron	x			
23. Kjeldahl Nitrogen	x			
24. Lead	x			
25. Lithium	x			
26. Magnesium	x			
27. Manganese	x			
28. Mercury	x			
29. Nitrate	x			
30. Nitrite	x			
31. Odor	x			
32. Oil & Grease	x			
33. Ortho-Phosphate	x			
34. Pesticides		x(M)		
35. pH	x	x(M)		
36. Potassium	x			
37. Selenium	x			
38. Silica	x			
39. Sodium	x			
40. Solids, Dissolved	x			
41. Solids, Suspended (sediment)			x(M)	x(0)
42. Sulfate	x			
43. Sulfide	x			
44. Turbidity	x		x(PC)	
45. Zinc		x(M)		
46. Complete element scan for all trace elements		x(M)		
47. Total Organic Carbon (TOC) If TOC > 10 mg/liter, then Dissolved Organic Carbon Suspended Organic Carbon Phenols Sulfur (acid extraction) Nitrogen (base extraction)				
48. Stream Flow (discharge)			x(M)	x(0)
49. Water Temperature			x(M)	x(0)

* - Depending on count, thorium 230, radium 226, and natural uranium may be required.
(M) - Major Gauging Stations Only.
(0) - All Gauging Stations Except Major Stations.
(PC) - Piceance Creek Gauging Stations Only.

uniform rate, water is admitted into the bottle throughout the profile. The source and conditions under which the sample is collected are recorded and attached to the bottle. Currently one liter containers (polyethylene, teflon, or other plastic) are being used by the USGS for storage and shipment to inorganic analyses.

Because many ions of trace elements will not remain in solution in the untreated sample until it is analyzed, several samples are taken at the same time. This allows duplicate samples for precision and determination of analytical error. It allows samples to be treated to inhibit chemical and physical reactions such as oxidation, reduction, precipitation, absorption, and ion exchange.

To remove turbidity, a source of interference, some samples are filtered through a 0.45 micron filter (0.45 micrometer membrane). From an untreated, filtered sample the following determinations are made:

(1) Boron
(2) Chloride
(3) Fluoride
(4) Hardness
(5) Lithium
(6) Nitrogen Nitrate
(7) Nitrogen Nitrite
(8) Phosphorus (all dissolved forms)
(9) Potassium
(10) Selenium
(11) Silica
(12) Sodium
(13) Solids dissolved
(14) Sulfate

Another sample is filtered and acidified with double distilled reagent-grade Nitric acid (HNO_3) to obtain on the sample a pH of 3.0 or less. Acidification minimizes the loss of solutes by oxidation or precipitation and by absorption by the container. From this sample the following determinations are made:

(1) Aluminum
(2) Arsenic
(3) Barium
(4) Cadmium
(5) Calcium
(6) Chromium
(7) Cobalt
(8) Copper
(9) Iron
(10) Lead
(11) Lithium
(12) Magnesium
(13) Manganese
(14) Molybdenum
(15) Nickle
(16) Potassium
(17) Silver
(18) Sodium
(19) Strontium
(20) Vanadium
(21) Zinc

An unfiltered and untreated third sample is stored in a cool, dark place to allow suspended material to settle. Determinations are made on aliquots of the clear supernatant solution for the following:

(1) Acidity
(2) Alkalinity
(3) Carbon dioxide (calculated)
(4) Color
(5) pH (lab)

A fourth sample unfiltered and well mixed is used to determine the following:

(1) Nitrogen, ammonia
(2) Nitrogen, organic
(3) Oxygen demand chemical
(4) Cyanide
(5) Phosphorus
(6) Solids, suspended
(7) Solids, volatile
(8) Turbidity

It is necessary to keep this sample well-chilled to prevent decomposition.

Field determinations include:

(1) Temperature
(2) pH
(3) Dissolved Oxygen
(4) Specific Conductance

Field determinations may include acidity and alkalinity. Additional samples are collected as necessary for radioactivity chemistry, DOC.

Accuracy of analysis is important in the comparison of data and in the interpretation of water chemistry. Some errors are unavoidable in analytical work. Errors may result from the reagents used, from the limitations of the method or instruments employed, or from the handling of the water sample prior to analysis.

It has been observed that, because of changes in the chemical composition of the water, the validity of the analytical work often decreases as a function of time following the opening of the sample. For example, the loss of carbon dioxide from solution converts bicarbonate to carbonate. Calcium carbonate may precipitate out of solution which would affect the validity of the pH, alkalinity, specific-conductance, calcium, hardness, and dissolved solids. This is more important in analyses of ground water than surface water because samples may be out of equilibrium with the environment.

Interference by one element or compound can affect the reading obtained on another. In spectrophotometric determinations, interferences result generally from the presence in the sample of dissolved or suspended foreign material that absorbs radiant energy affecting the reading. Similarly formation of salts by the element being examined can give a faulty reading by reducing the amount of the element available. Unusually high amounts of dissolved solids can interfere with the determination of trace elements to the point of raising the lower detectable limit of the analytical method. Dilution of the sample to avoid this situation also serves to dilute the amount of trace elements available for analyses. Several procedures for removal of interferences may be utilized. The choice depends on the element being analyzed and the analytical technique.

In this regard it should be pointed out that trace elements may occur in such quantities that their presence may go undetected. The amount of a given element present would be less than the detection limits of the analytical method used within the limits of the water sample as described above. For example, if in two successive sampling periods the amount of barium analyzed is reported as "<100" micrograms per liter and "<200" micrograms per liter, it should not be assumed that there was twice as much barium present on the second occasion as on the first. In fact there may have been no barium present at all. The less than symbol, <, indicates that if barium were present in the sample, its quantity was less than the stated amount and less than the detectable analytical limit.

Table 3-24 presents a list of the parameters measured along with units, method of analysis, and limits of quantitative presentation. As a check on accuracy of determination, The Oil Shale Company's laboratory performed a major constituent analysis on the same water sample analyzed by the USGS laboratory. Comparison between the laboratories is excellent (Table 3-25).

3.1.5.5 Results and Discussion

3.1.5.5.1 Continuous Measurements

In addition to stream flow, continuous records are maintained at the major stations for pH, dissolved oxygen, conductance, and temperature. For one reason or another records are not completely continuous throughout the year. Records for water years 1975 and 1976 have been plotted as a time series and are presented in the appendix. Minimums and maximums for Piceance Creek and for the tributaries are shown in Table 3-26.

The range of conductance values is greatest in Piceance Creek below the Tract, Station USGS 09306061. The range in Willow Creek, Station USGS 09306058, is second greatest, almost three times greater than on Piceance Creek above the Tract, Station USGS 09306007. The range of conductance values is quite low along Stewart Gulch, Stations USGS 09306022 and USGS 09306025. Except for two extremely low values in February 1976, the range on Stewart Gulch would average about 400 μmhos. On February 10 and again on February 12 rainfall on the snowpack caused sufficient runoff to result in a recordable stream flow event at Station 09306025. Snow melt water running over frozen ground caused a baseline minimum to be set at this station.

Table 3-24

LIST OF ELEMENTS & COMPOUNDS ANALYZED FOR IN SURFACE WATER

Parameters	Symbols	Lowest Value Reported and Unit	Coded Significant Figures Reported	Method
Alkalinity	$CaCO_3$	1 MGL	6	3a
Aluminum	Al	10 MGL	2	1 *
Ammonia	as N			2
Arsenic	Ar	1 MGL	1	1
Barium	Ba	100 UGL	3	1 *
Beryllium	Be	10 UGL	2	1 *
Bicarbonate	HCO_3	1 MGL	6	
Bismuth	Bi			*
Boron	B	10 UGL	2	2 *
Cadmium	Cd	1 UGL	1	1 *
Calcium	Ca	0.1 MGL	4	1
Carbonate	CO_3	1 MGL	6	
Chloride	Cl	.1 MGL	4	
Chromium	Cr	10 UGL	2	1 *
Cobalt	Co	1 UGL	1	1 *
Coliform, Total & Fecal				
Color (Not Precise)			9	3e
Conductivity, Specific		**		3d
Copper	Cu	1 UGL	1	1
Cyanide	Cn	10 UGL	2	2
Dissolved Oxygen	DO			
Fluoride	Fl	.1 MGL	4	3b
Gallium	Ga	UGL		*
Germanium	Ge	UGL		*
Hardness (Ca, Mg)		MGL		Calculated
Iron	Fe	10 UGL	2	1,2 *
Kjeldahl Nitrogen		.01 MGL	7	
Lead	Pb	1 UGL	1	1 *
Lithium	Li	10 UGL	2	1 *
Magnesium	Mg	0.1 MGL	4	1
Magnanese	Mn	10 UGL	2	1 *
Mercury	Hg	1 UGL	1	1
Molybdenum	Mo	1 UGL	1	1 *
Nickel	Ni	1 UGL	1	1 *
Nitrate	NO_3	.01 MGL	7	2
Nitrite	NO_2	.01 MGL	7	2
Odor				
Oil & Grease		1 MGL	5	
Ortho-Phosphorus	PO_4	.01 MGL	7	2
Pesticides		.01 UGL	8	
pH		1 decimal		3c
Potassium	K	0.1 MGL	4	1
Selenium	Se	1 UGL	1	1
Silica	$Si0_2$	0.1 MGL	4	1,2
Silver	Ag	1 UGL	1	1
Sodium	Na	0.1 MGL	4	1
Solids, Dissolved	TDS	1 MGL	6	4
Solids, Suspended		1 MGL	6	
Strontium	Sr	10 UGL	2	1 *
Sulfate	SO_4	0.1 MGL	4	2
Sulfide	SO_2	0.1 MGL	4	5
Temperature (^oC)				
Tin	Sn	1 UGL	1	*
Titanium	Ti	1 UGL	1	*
Turbidity		NTU	10	
Vanadium	V	1 UGL	1	2 *
Zinc	Zn	10 UGL	2	1 *
Zirconium	Zr	10 UGL	2	
Radioactivity				
Gross Alpha (pcl)				
Radium 226				
Gross Beta				
Thorium 230				
Uranium				
Total Organic Carbon (TOC)				

LEGEND FOR TABLE 3-24

LOWEST VALUE REPORTED AND UNIT

** <1000 UMHOS whole number; ≥1000 UMHOS 3 significant figures

SIGNIFICANT FIGURES REPORTED

Code		Code	
1	<10 ug/1: 1 ≥10 ug/1: 2	5	<10 mg/1: 1 ≥10 mg/1: 2
2	<100 ug/1: 1 ≥100 ug/1: 2	6	<1000 mg/1: whole numbers ≥1000 mg/1: 3
3	<1000 ug/1: 1 ≥1000 ug/1: 2	7	<0.10 mg/1: 1 ≥0.10 mg/1: 2
4	<1.0 mg/1: 1 ≥1.0 mg/1: 2		

8 For most Pesticide analyses the lowest reported value is 0.01 ug/1, concentrations less than 0.10 ug/1 are reported to one significant figure and concentrations greater than or equal to 0.10 ug/1 are reported to two significant figures. The exceptions to the above rule are chlordane, toxaphene, PCB and PCN. The lowest reported value for these compounds is 0.1 ug/1, concentrations less than 1.0 ug/1 are reported to one significant figure and concentrations greater than or equal to 1.0 ug/1 are reported to two significant figures.

9 Color

Color Unit	Record units to nearest
1-50	1
51-100	5
101-250	10
251-500	20

10 Turbidity

Turbidity Range (NTU)	Report to nearest
0.0-1.0	0.05
1-10	0.1
10-40	1
40-100	5
100-400	10
400-1000	50
>1000	100

METHOD

* These parameters are also determined by emission spectrographic techniques with differing detection limits.

Numbers indicated are for: 1. atomic absorption spectrometric, 2. colorimetric methods, 3. electrometry, 3a. electrometric titration, 3b. ion-selective electrode, 3c. glass electrode, 3d. Wheatstone bridge, 4. gravimetry, 5. titrimetry iodometric

Radioactive substances determined by methods outlined in USGS open file report 76-560.

Total organic carbon-A water sample is treated with persulfate and acid to oxidize the organic carbon to carbon dioxide. The CO_2 produced is subsequently analyzed using infrared spectrometry. (Oceanography International Analyzer)

A bottom material sample is dried, ground, sieved and an aliquot weighed. This sample is burned in an inductive furnace (LECO Analyzer) and the CO_2 is measured by a thermal conductivity detector.

Pesticides analyses-The insecticides are extracted from water with hexane, "cleaned-up" on alumina, and analyzed by gas cromatography with electron capture detectors.

Herbicides, after sample acidification, are extracted from water with ether, esterified with BF_3-methanol, "cleaned" on florisil, and analyzed by gas chromatography with electron capture detectors.

Bottom material is weighed, extracted with acetone and hexane for insecticides or acetone and ether for herbicides. The analysis from this point on is essentially the same as the water-pesticide procedure.

Table 3-25

COMPARISON OF RESULTS FROM TOSCO & USGS LABORATORIES, GROUND WATER QUALITY

Component, mg/l	Piceance Creek Below Rio Blanco (No. 09306007, 1-15-75)		Piceance Creek Above Hunter Creek (No. 09306061, 1-16-75)	
	USGS	TOSCO	USGS	TOSCO
Sodium	130.	124.	140.	141.
Potassium	3.4	3.4	2.6	2.6
Calcium	74.	65.	79.	72.
Magnesium	46.	51.	64.	75.
Sulfate	160.	167.	290.	294.
Carbonate	0.	9.	0.	5.
Bicarbonate	552.	523.	545.	545.
Chloride	16.	14.	12.	13.
Fluoride	1.2	1.2	0.7	0.7
Borate	0.9	0.8	0.8	0.8
Cations, meq/l	13.22	12.93	15.37	15.97
Anions, meq/l	12.92	12.83	15.35	15.65
% Difference	1.1	0.4	0.1	1.0
Silica, mg/l	17.	17.	17.	17.
pH	8.1	8.4	8.1	8.4
Calculated TDS, mg/l	719.	709.	873.	888.

Table 3-26 CONTINUOUS WATER QUALITY PARAMETERS STREAM FLOW OIL SHALE TRACT C-b

Parameter		Piceance Creek						Tributaries					
		Minimum			Maximum			Minimum			Maximum		
	Yr	Value	Date	Station	Value	Date	Station	Value	Date	Station	Value	Date	Station
Specific Conductance	1975	925	5/22	007	4000	12/3	061	875	5/22	058	3500	12/6	058
(UMHOS)	1976	403	4/14	007	1820	1/13	061	110	2/10	025	1980	11/12	022
Dissolved Oxygen	1975	5.5	3/7	061	14.4	11/6	007	7.0	4/29 7/2	022 058	14.0	12/30	022
(MGL)	1976	5.3	10/1	061	15.2	3/21	061	3.1	7/29	058	13.1	3/12	022
Temperature	1975	0	1/3 12/8	061 007	21	7/2	061	0	11/20 1/12	025 058	21	7/9	025
°C	1976	-1	12/18	061	22.5	7/24	007	-.6	10/23	025	22	7/26	025
pH	1975	7.7	1/3 2/3	007 061	9.2	5/7	061	6.4	12/1	058	9.4	5/7	058
	1976	7.6	7/28	007	8.7	12/16 6/24 8/19	007 007 007	7.8	10/7 7/13	022 022	8.9	12/17	058

Even though the 1975 minimum and maximum were recorded at Station 09306022 on Stewart Gulch, the dissolved oxygen readings are fairly constant at this station. Station 09306007 on Piceance Creek above the Tract shows a narrow band of values. The dissolved oxygen at Willow Creek, Station 09306058 and at Piceance Creek above Hunter Creek, Station 09306061 below the Tract show the greatest variability. The lowest low (3.1 mg/l) was on Willow Creek. The highest high (15.2 mg/l) was at Piceance Creek below the Tract.

Temperature ranges are about the same at all stations except Stewart Gulch 09306022. The yearly range is 12 Centigrade degrees from minimum to maximum. Ignoring the extremes, the yearly range reduces to eight degrees with a maximum monthly range of one and one-half degrees. The fairly constant temperature is, of course, indicative of the source from spring flows. Maximums are attributed to runoff from rainfall associated with storm fronts or convective showers.

The range of pH values was greatest on Willow Creek and least on Stewart Gulch. On Stewart Gulch, 1976 values are much more constant than 1975 values. Except for lower readings in October and November 1975 and July 1976, pH is maintained at about 8.3 throughout the 1976 water year. At no station is the variability very great.

Time series plots do not show relationships with other variables. Graphs of the concentrations of dissolved solids (mg/l) as a function of discharge are shown in Figure 3-19 for the three stations along Piceance Creek. As can be seen, for a given discharge the amount of TDS increases downstream indicating degradation of water quality downstream. The slope of the curves indicates an increase in ions at low flows. Another well known correlation is that between specific conductance and dissolved solids. For most water suitable for irrigation, the relationship is:

specific conductance X 0.65 ±0.1 = dissolved solids.

This relationship for waters on or near the Tract is shown in Figure 3-20. Specific conductivity measures the ability of a solution to carry electrical current and is an indirect measure of total dissolved solids. For a stream which fits the simple dilution model for flow, conductivity will decrease with increasing flow because the increased flow resulting from surface runoff will carry a lower TDS load. Flow in the mainstream of Piceance Creek, as illustrated by Station 09306007 (Figure 3-21), does show a slight trend toward lower conductivity with increasing flow, thus tending to confirm the dilution model for stream flow. Flow in the tributaries, however, illustrated by the Willow Creek Station 09306058 (Figure 3-22), exhibits almost uniform conductivity regardless of flow. This indicates that these streams carry little other than dissolved load.

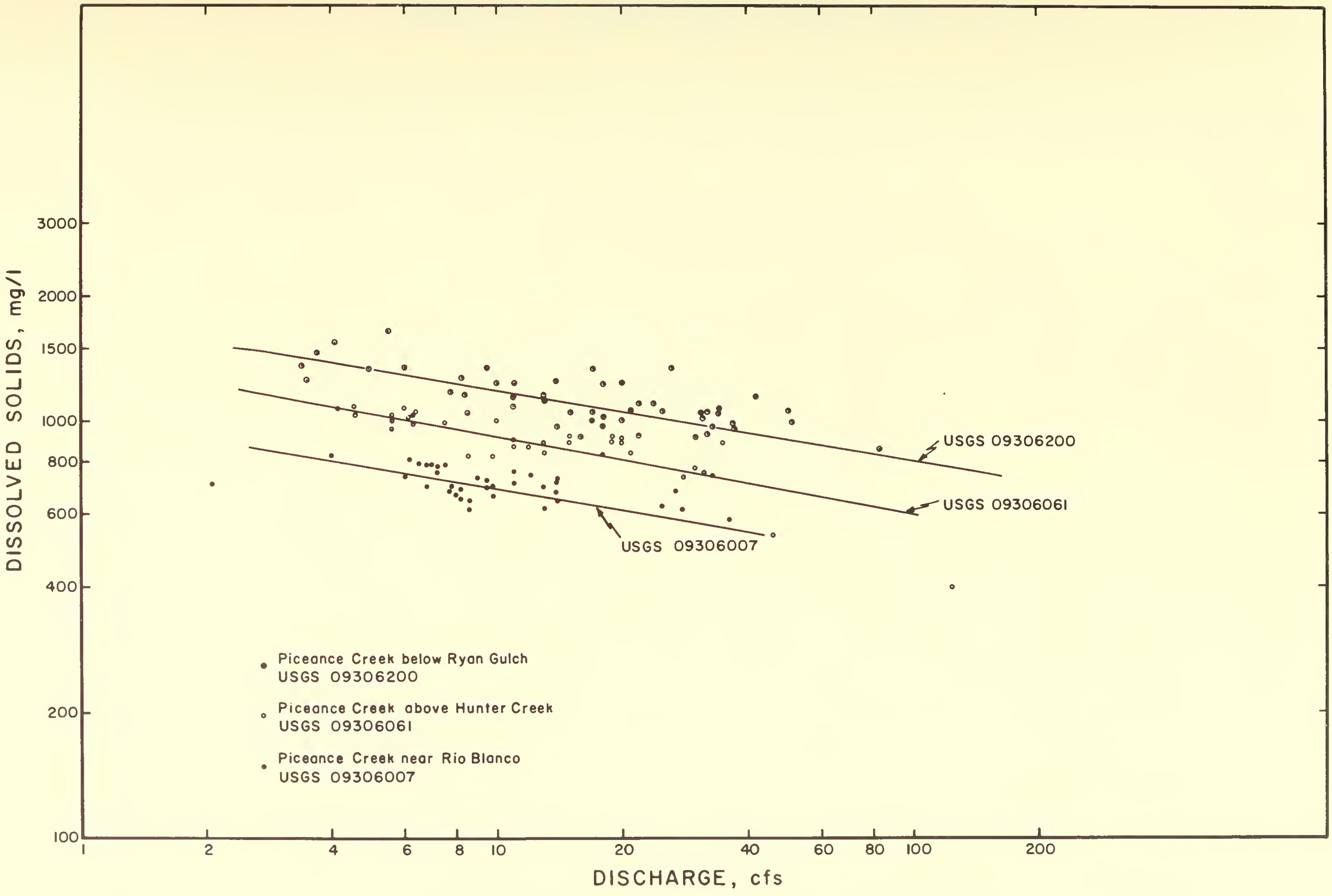


FIGURE 3-19 FLOW VS TOTAL DISSOLVED SOLIDS
PICEANCE CREEK

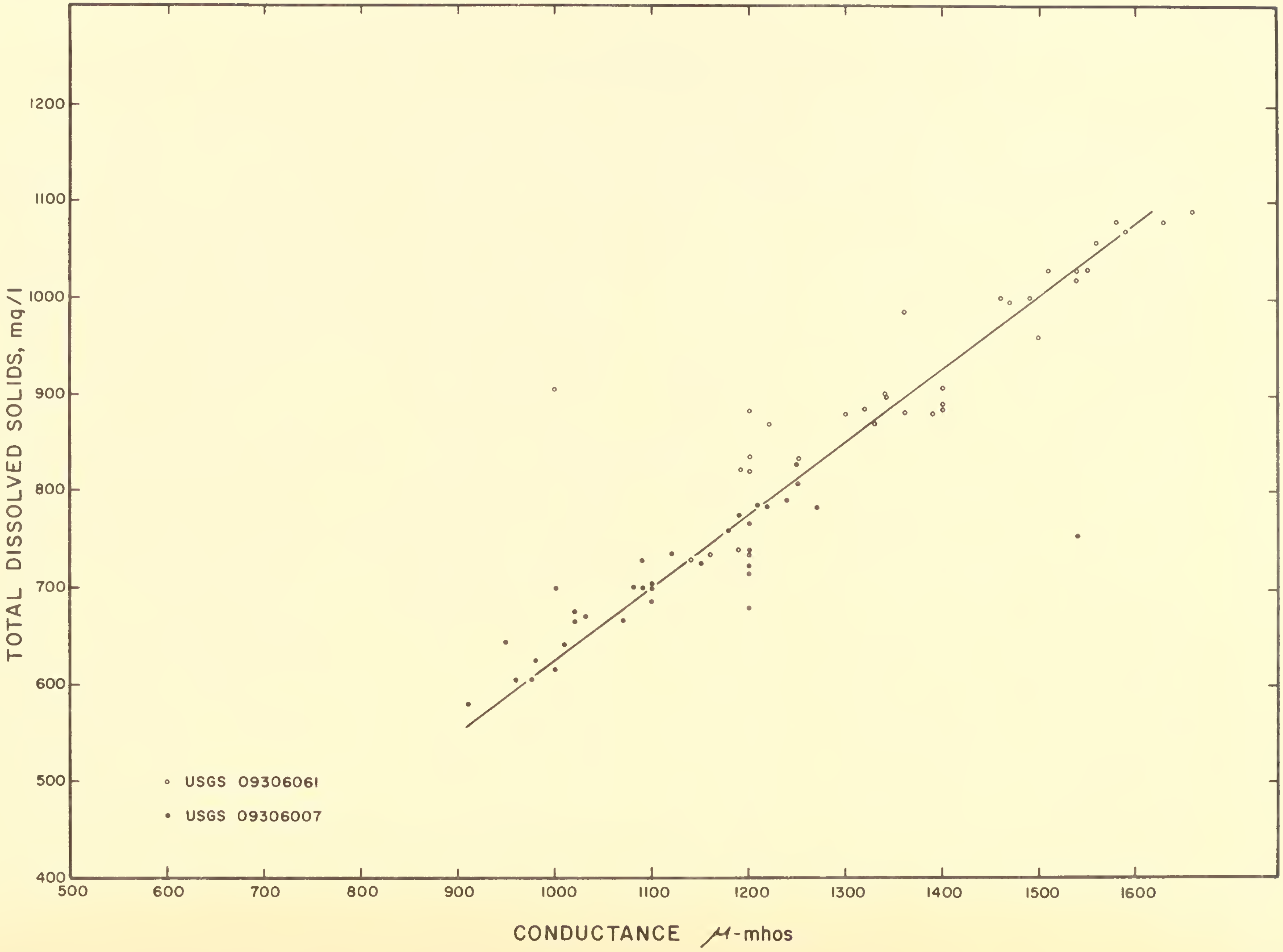


FIGURE 3-20 CONDUCTANCE VS TOTAL DISSOLVED SOLIDS
PICEANCE CREEK

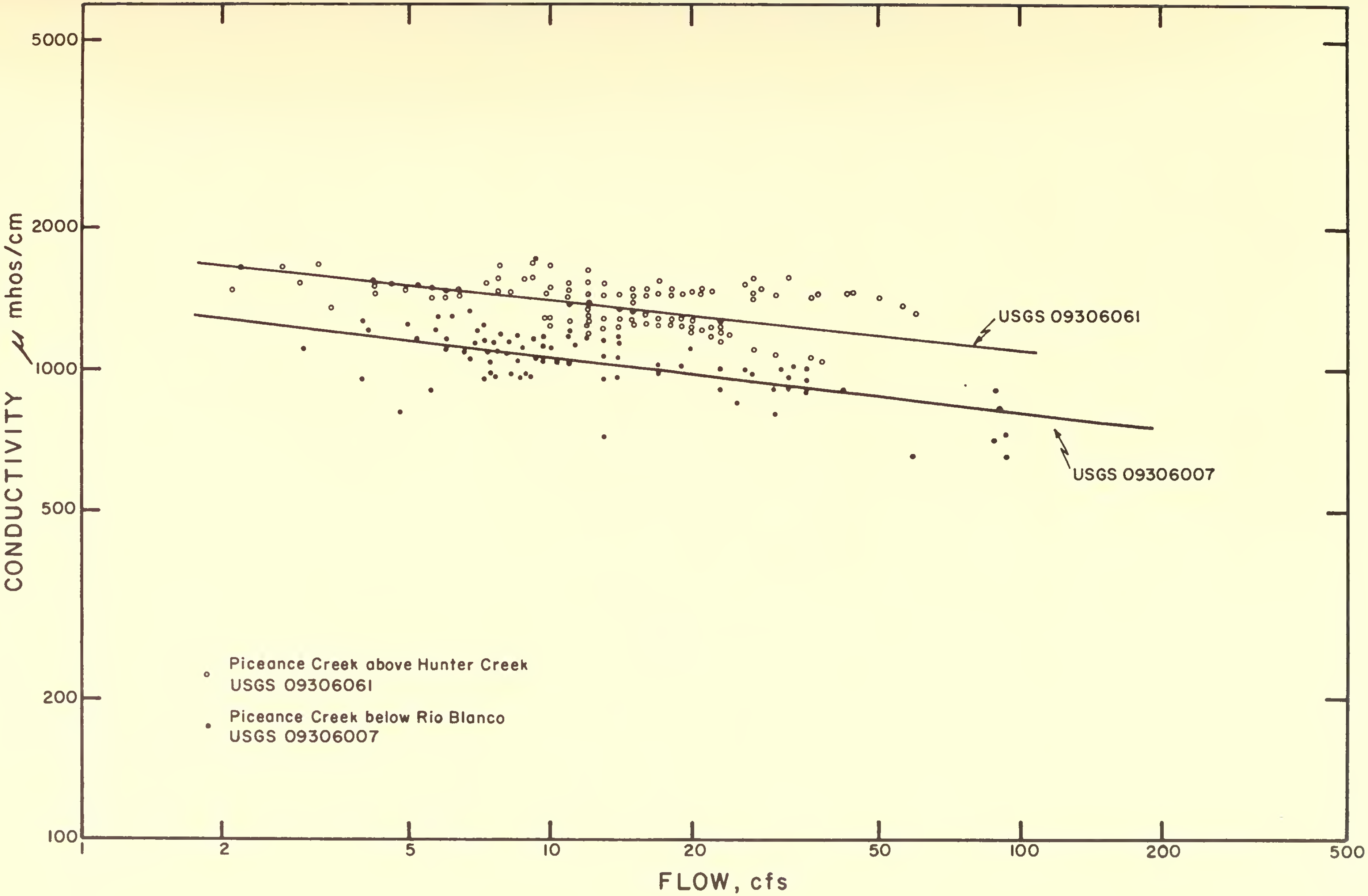


FIGURE 3-21 FLOW VS CONDUCTIVITY
PICEANCE CREEK

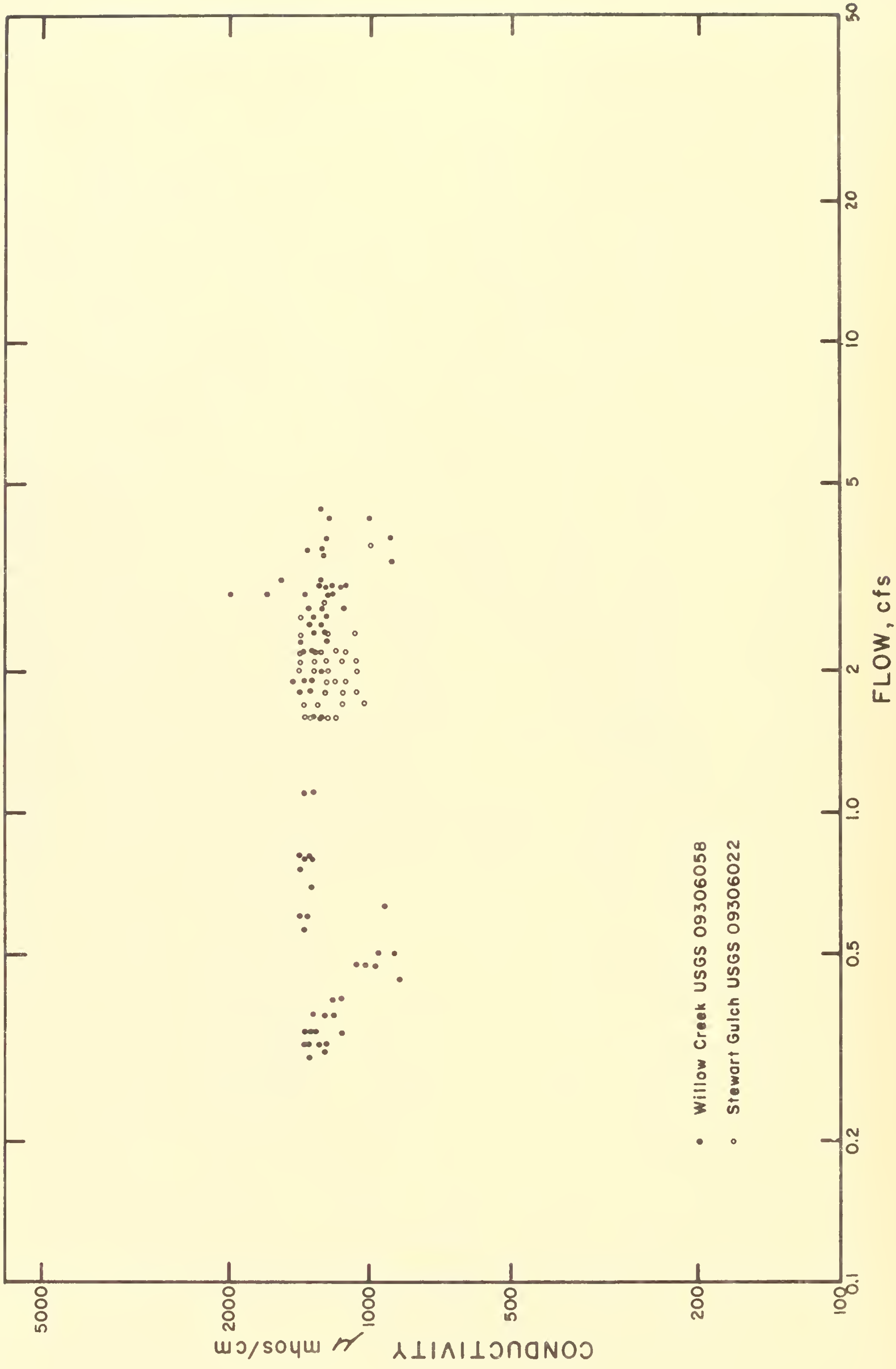


FIGURE 3-22 FLOW VS CONDUCTIVITY
PICEANCE CREEK TRIBUTARIES

Two-variable correlations between specific conductance and the major ions were run by the USGS. The coefficient of correlation for each of the major ions at the various stations is shown in Table 3-27. Correlation coefficients are highest at Station 09306025 on the West Fork of Stewart Gulch and are lowest at Station 09306058 on Willow Creek. The correlation coefficient between total dissolved solids and conductance is also highest on West Fork of Stewart Gulch and lowest on Willow Creek. At this time, there is no explanation for the differences except perhaps that the range in amounts of TDS and specific conductance is narrowest on Stewart Gulch.

It would appear that measurement of specific conductance, which is made continuously at the major stations, will allow a reasonably accurate prediction of the quantity of some of the major ions present in the surface water, especially when the value of specific conductance is within one standard deviation of its mean. It is relationships such as these that should allow a reduction in sampling frequency.

The two years of baseline data for the continuous recording stations are classified as preliminary by the USGS. The data base, in fact, is not continuous because the instruments have seldom operated continuously. Except for discharge, no records are completely continuous for the two years of baseline. Availability of continuous data at most stations varies. Data availability for 1976 is best at 09306061 below the Tract where only about 25 percent of the record is missing and at 09306022 on Stewart Gulch where missing record varies from 17 percent for temperature and pH to 33 percent for specific conductance. The shortest record is at 09306058 on Willow Creek where over 60 percent of the continuous data is missing. Overall records for specific conductance and for dissolved oxygen are the shortest with an average of 40 percent of the 1976 record missing.

Nevertheless, there are enough data available to plot some of these variables against discharge to ascertain predictable relationships. Plots of discharge vs. sediment concentration show a wide spread of points but nevertheless, show a distinct linear trend when plotted on log-log paper (Figure 3-23). Perhaps the most interesting trend is that the curves for 09306007, 09306058, and 09306061 appear parallel even though the values for 09306058 are one order of magnitude less than the values for 09306007 and 09306061. Furthermore, the plot for Station 09306022 indicates a completely different pattern. It is generally observed that suspended-sediment concentration of river water shows a sharp increase when discharge increases (Hem 1974) as in Figure 3-23 for 09306007 and 09306061,but the pattern at 09306022 is vertical (slope of 90°) indicating that flow has little effect on the amount of sediment movement in Stewart Gulch. This may be an effect of the quantity of sediment since, in the plots of the other stations, a vertical tendency is exhibited for those points where sediment load is less

Table 3-27

COEFFICIENT OF CORRELATION BETWEEN CONDUCTANCE AND MAJOR IONS

Station Number	No. Data Points	HCO_3	Ca	Cl	K	Mg	Na	SO_4	Sum DS
09306007	53	.789	.631	.406	.073	.667	.803	.642	.832
09306025	36	.945	.824	.596	.238	.964	.970	.948	.979
09306058	58	.554	.224	.193	.478	.543	.538	.590	.672
09306061	49	.868	.341	.635	.342	.862	.909	.843	.914
09306200	31	.814	-.027	.020	.141	.764	.781	.814	.840
09306222	29	.737	-.443	.766	.330	.705	.906	.817	.871

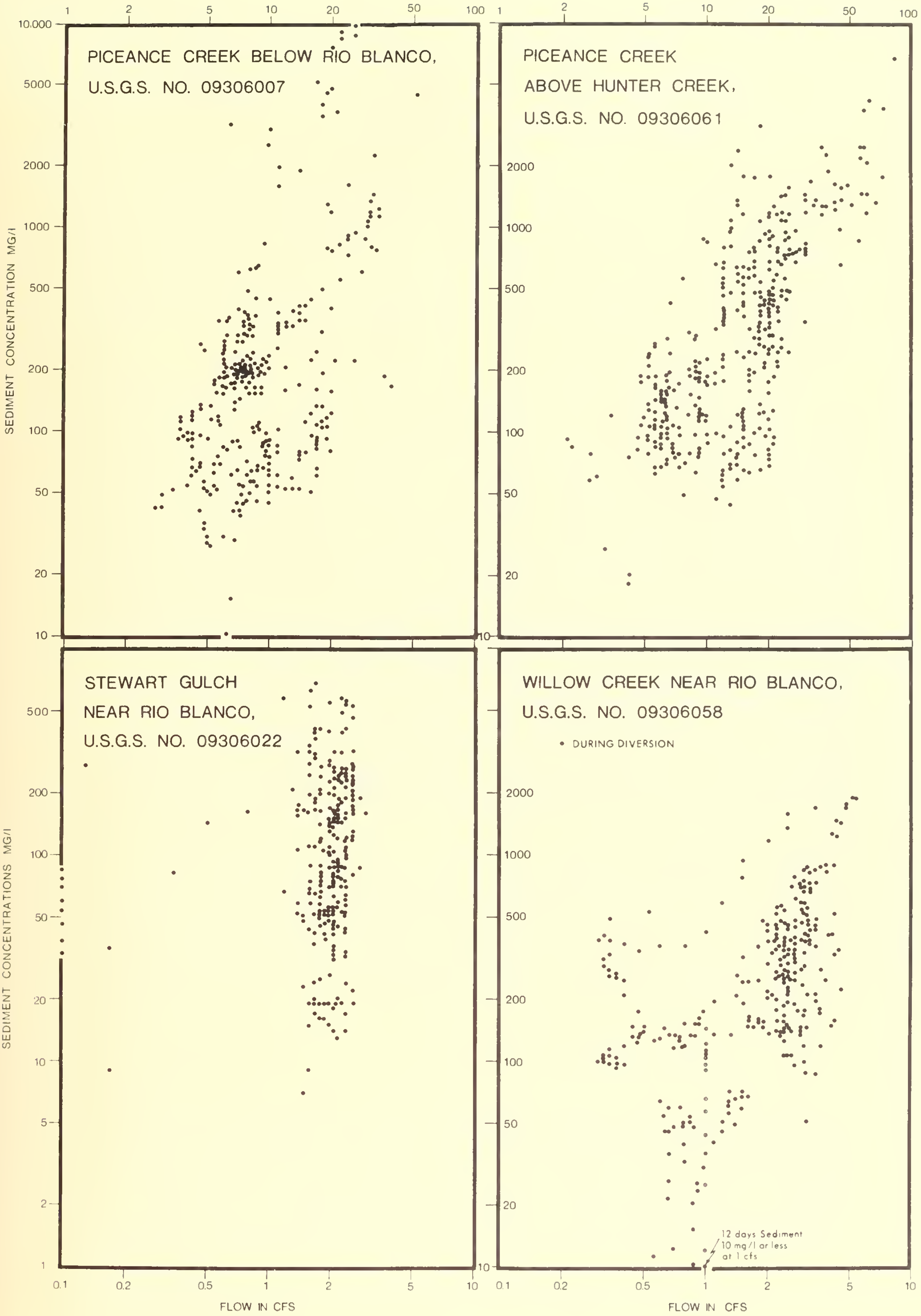


FIGURE 3 23 SEDIMENT CONCENTRATION AS A FUNCTION OF FLOW than 200 mg/l. This may also be an effect of flow since the range in flow is only 2.9 cfs. More data are necessary before actual cause and effect can be ascertained.

Two patterns can be seen in the data on stream temperature. A distinct diurnal pattern with afternoon peaks and early morning lows is exhibited in Figure 3-24. The extremes of this phenomenon are to be expected in a shallow stream and the shallowness of Piceance Creek is an explanation for the maximums registered at these stations. In addition, the shallowness of the stream and the high solar radiation inherent in the climate of western Colorado give rise to the generally high maximum water temperatures throughout the year.

The solubility of oxygen in water is a function of temperature and pressure and because the chief source of oxygen in surface water is the atmosphere, the oxygen content of water and meteorological conditions are interwoven. Figure 3-25 shows dissolved oxygen as a function of temperature. Other factors influencing the oxygen content are water chemistry, turbulence of flow, and biological activity, such as fresh water biota or organic material load. Oxygen is contributed indirectly as a by-product of photosynthesis (Hem 1970) and some oxygen is depleted by BOD and COD loads. Dissolved oxygen readings are indicators of the biochemical condition of a stream. However, because of the rapidly changing conditions influencing the intake or consumption, the oxygen content of surface water is highly transient. A dissolved oxygen value is meaningful only at the sampling station and only for a brief interval of time. With the minimum data available it appears that after a low during the winter, dissolved oxygen reaches a maximum in March prior to the summer increase in temperature and biologic activity. It is not anticipated that oxygen is a limiting factor for fish life in the local streams. It may be that elevated total dissolved solids are of much greater concern.

All constituents exhibit changes through the seasons; pH is no exception. One should expect an increase in the pH of river water because of the photosynthesis by aquatic vegetation. Photosynthesis, less active in the winter, causes depletion of the dissolved carbon dioxide, increasing pH and decreasing the carbonate-bicarbonate ratio. Theoretically, there is no carbonate present at pH values of 8.3 and below.

3.1.5.5.2 Monthly Analysis

During the first year of baseline, water samples were taken every two weeks and analyses were made for an extensive list of constituents. Review and evaluation of the first year's data showed that quantities of most constituents varied within narrow limits. With the beginning of the 1976 water year, a revised schedule of water monitoring activities was adopted with the

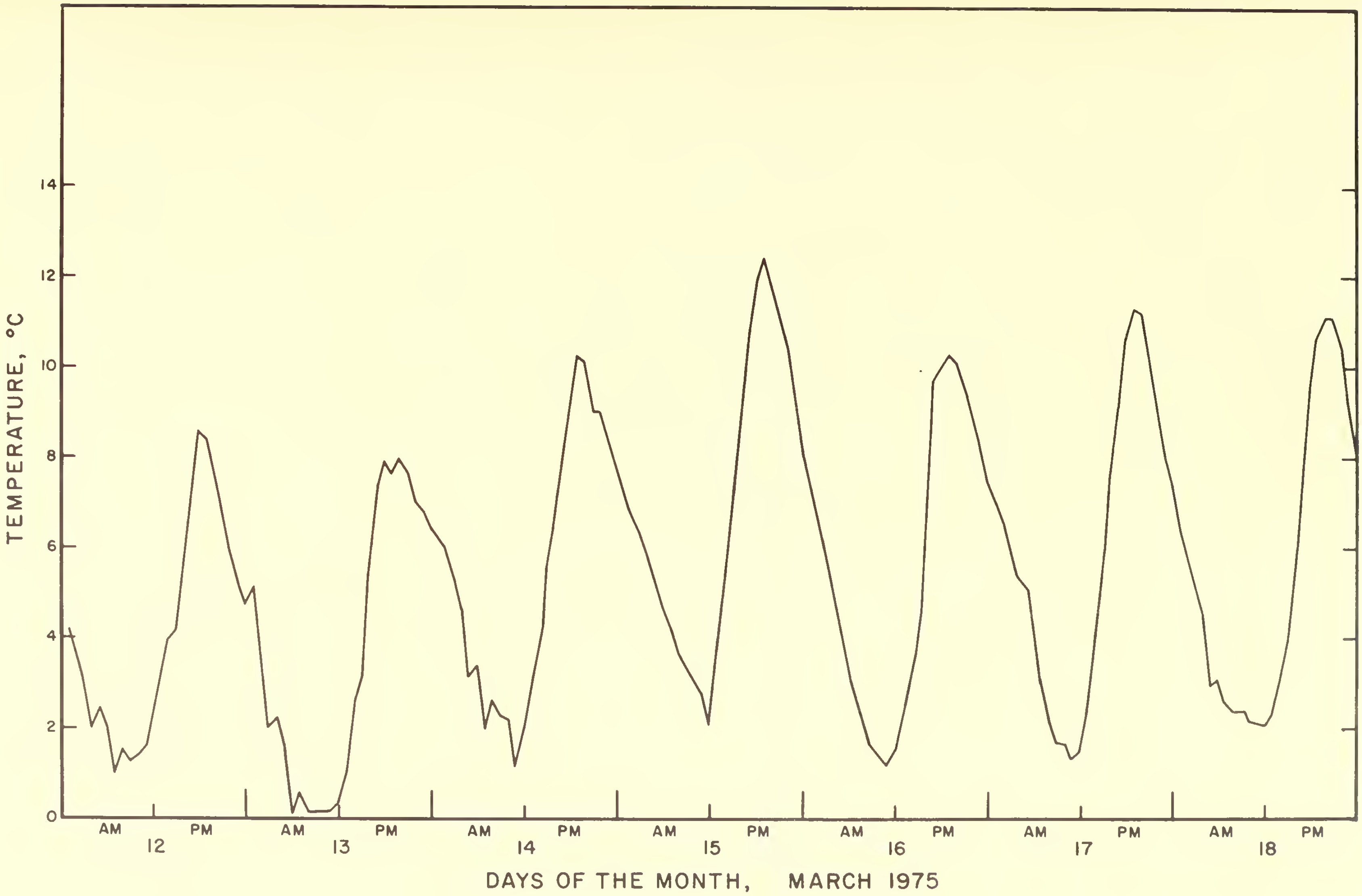


FIGURE 3-24 DIURNAL VARIATION IN WATER TEMPERATURE AT PICEANCE CREEK BELOW RIO BLANCO, USGS STATION 09306007

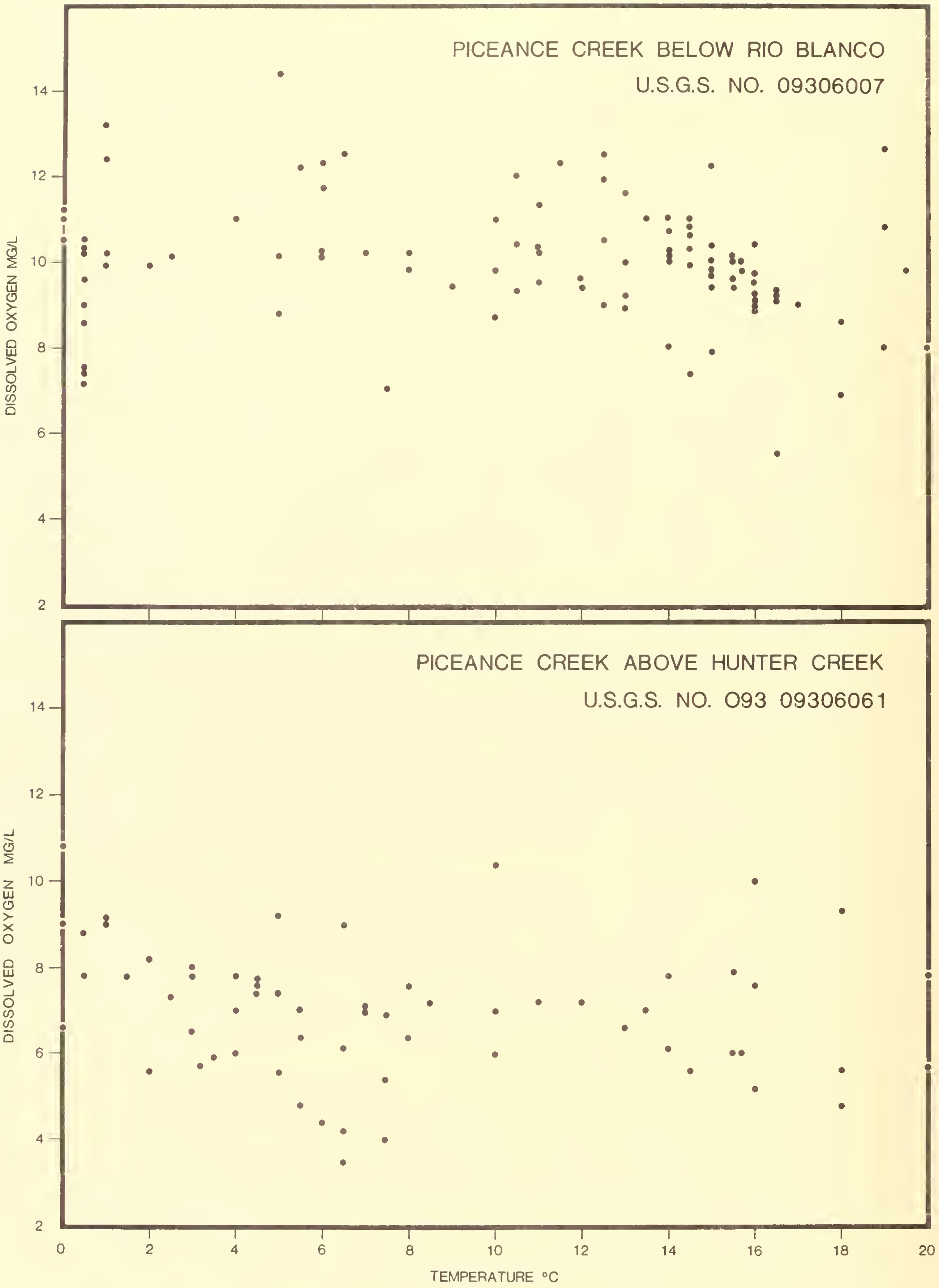


FIGURE 3-25 DISSOLVED OXYGEN AS A FUNCTION OF TEMPERATURE

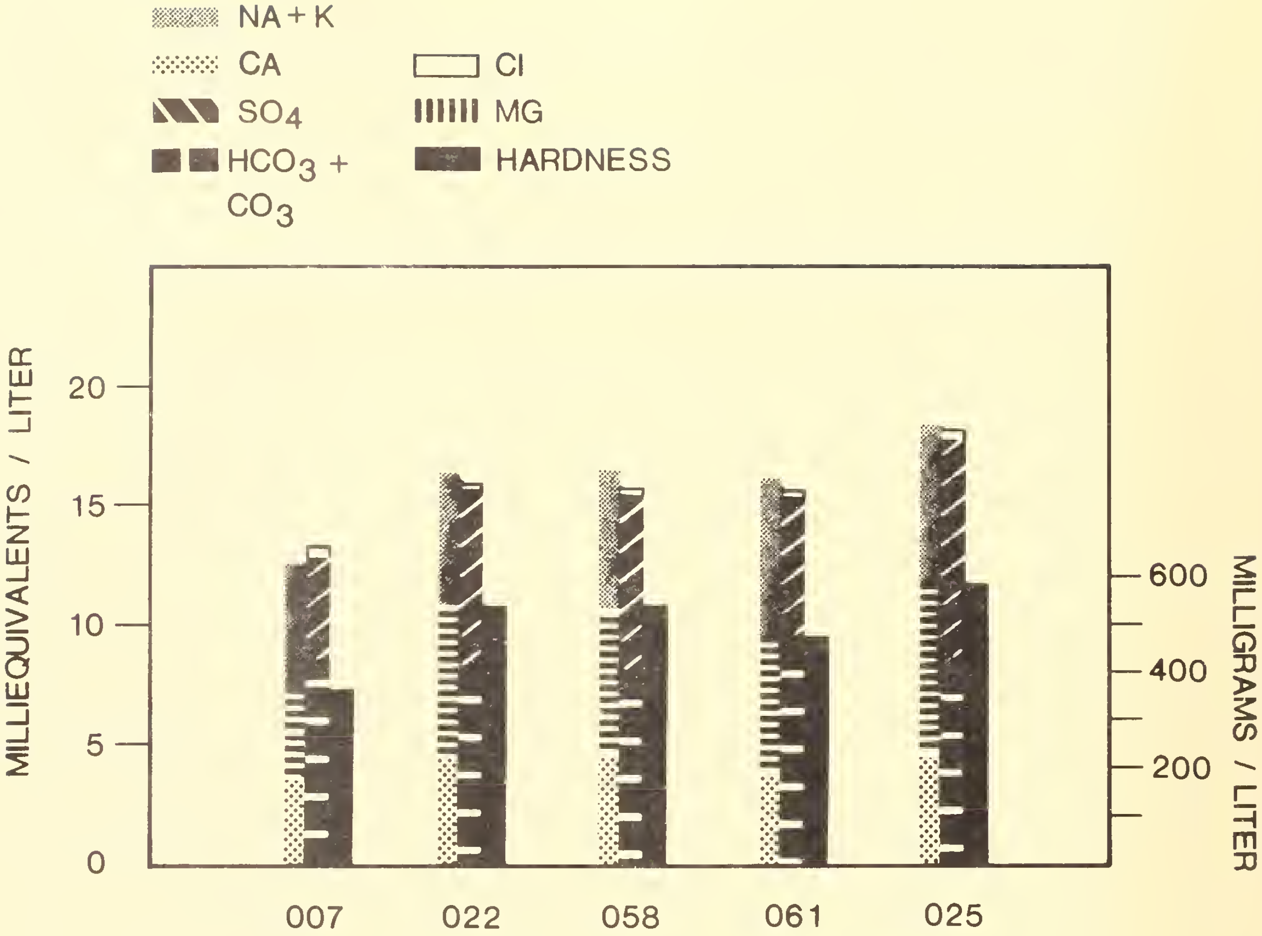
approval of the Area Oil Shale Supervisor's Office. Sampling frequency for trace elements and pesticides was continued quarterly but the sampling frequency for major constituents was reduced to a monthly basis.

Dissolved cations (positive charged ions) which constitute a major part of the dissolved solids are calcium, magnesium, sodium, and potassium. Major anions (negatively charged ions) are sulfate, chloride, nitrate, and those that contribute to alkalinity, bicarbonate, and carbonate.

Figure 3-26 shows the mean concentration for the major ionic constituents in milliequivalents and the water hardness as determined at the four major gauging stations and at Station USGS 09306025. All waters have quite high TDS levels with the tributaries exhibiting higher TDS than Piceance Creek. Magnesium and sodium are the dominant cations; sodium is dominant in Piceance Creek as shown at Stations 09306007 and 09306061, and magnesium is the dominant cation in the Piceance Creek tributaries of Stewart Gulch and Willow Creek. Bicarbonate is the dominant anion at all locations except for West Fork of Stewart Gulch where sulfate is the dominant anion.

Concentrations of the major constituents in surface streams are very similar to those in the water of the alluvial wells. As in the alluvial wells, the surface water in West Fork of Stewart Gulch is the only surface stream of record in the study area where sulfate concentrations are greater than bicarbonate. While there is a rather constant ratio of bicarbonate to sulfate with sodium bicarbonate dominant along Piceance Creek, the waters of the West Fork of Stewart Gulch are slightly dominant in magnesium sulfate. Hem (1970) suggests that the principal cation in most fresh water is calcium and that rivers in the more arid regions tend to have much higher ionic concentrations of dissolved calcium. Within the C-b Tract region, however, calcium is generally third in abundance behind sodium and magnesium. Plots of the major constituents over the baseline, i.e., water year 1975 and 1976, are shown in Figures 3-27 to 3-32.

Calcium (Figure 3-27) does not vary much with changes in flow or between stations. During the irrigation season, when flows at most stations are dramatically reduced, the concentration of calcium remains almost constant. The mean concentration of calcium in Piceance Creek varies from 70 mg/l at 09306007 to 77 mg/l at 09306061. Mean concentration of calcium in Willow Creek is 92 mg/l and in the waters of Stewart Gulch, it is 90 mg/l. Lowest observed concentrations were 16 mg/l at 09306061 in Piceance Creek and 17 mg/l at 09306025 in the waters of the West Fork of Stewart Gulch. The low in Piceance Creek occurred on June 25, 1976, and the low in Stewart Gulch occurred February 10, 1976.



COMPARISON OF MAJOR IONS

AND HARDNESS OF SURFACE WATERS

ON TRACT C-b PICEANCE CREEK COLORADO

FIGURE 3-26

CALCIUM CONCENTRATIONS TRACT C-b
1975-1976 WATER YEAR

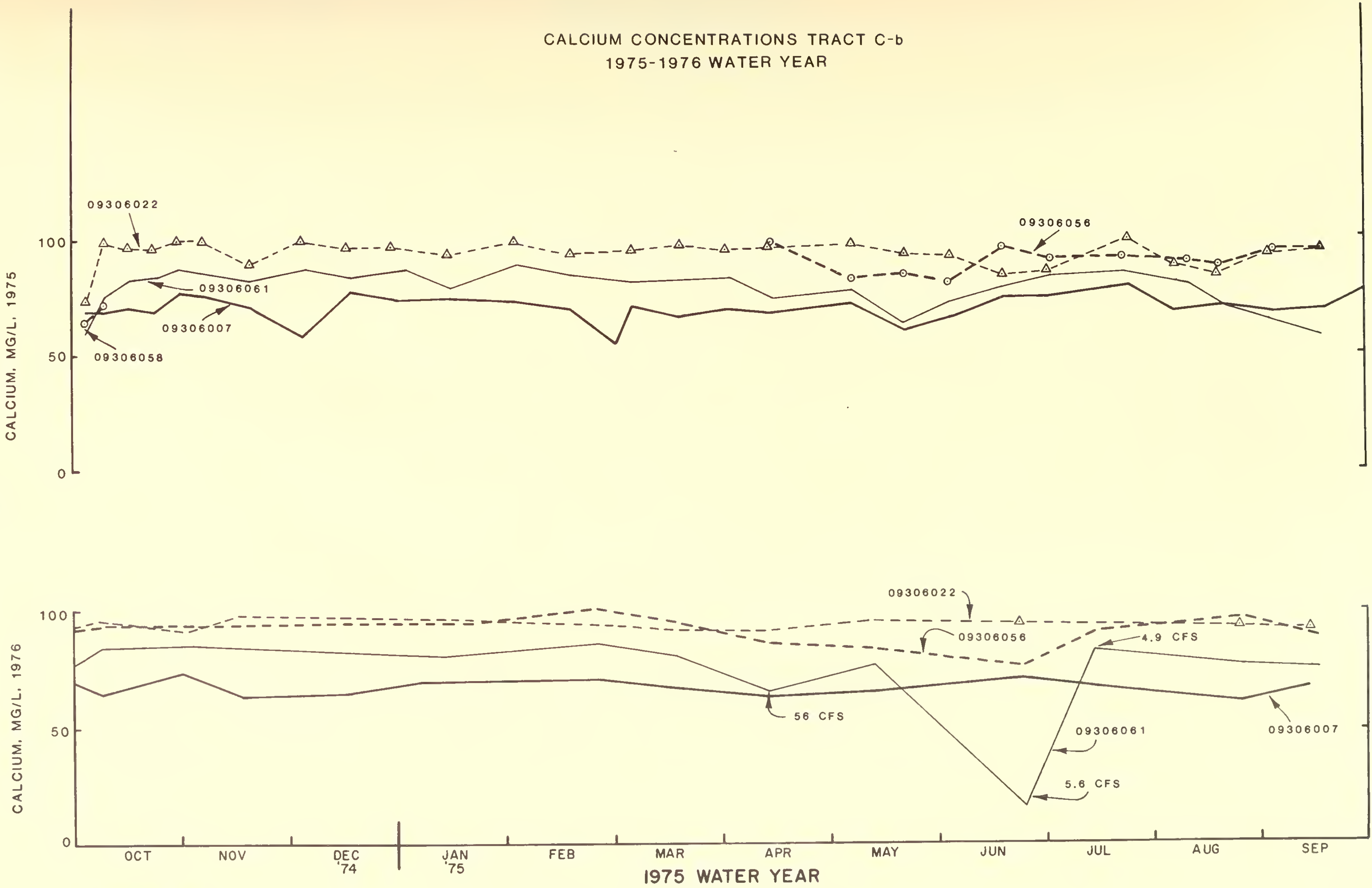


FIGURE 3-27

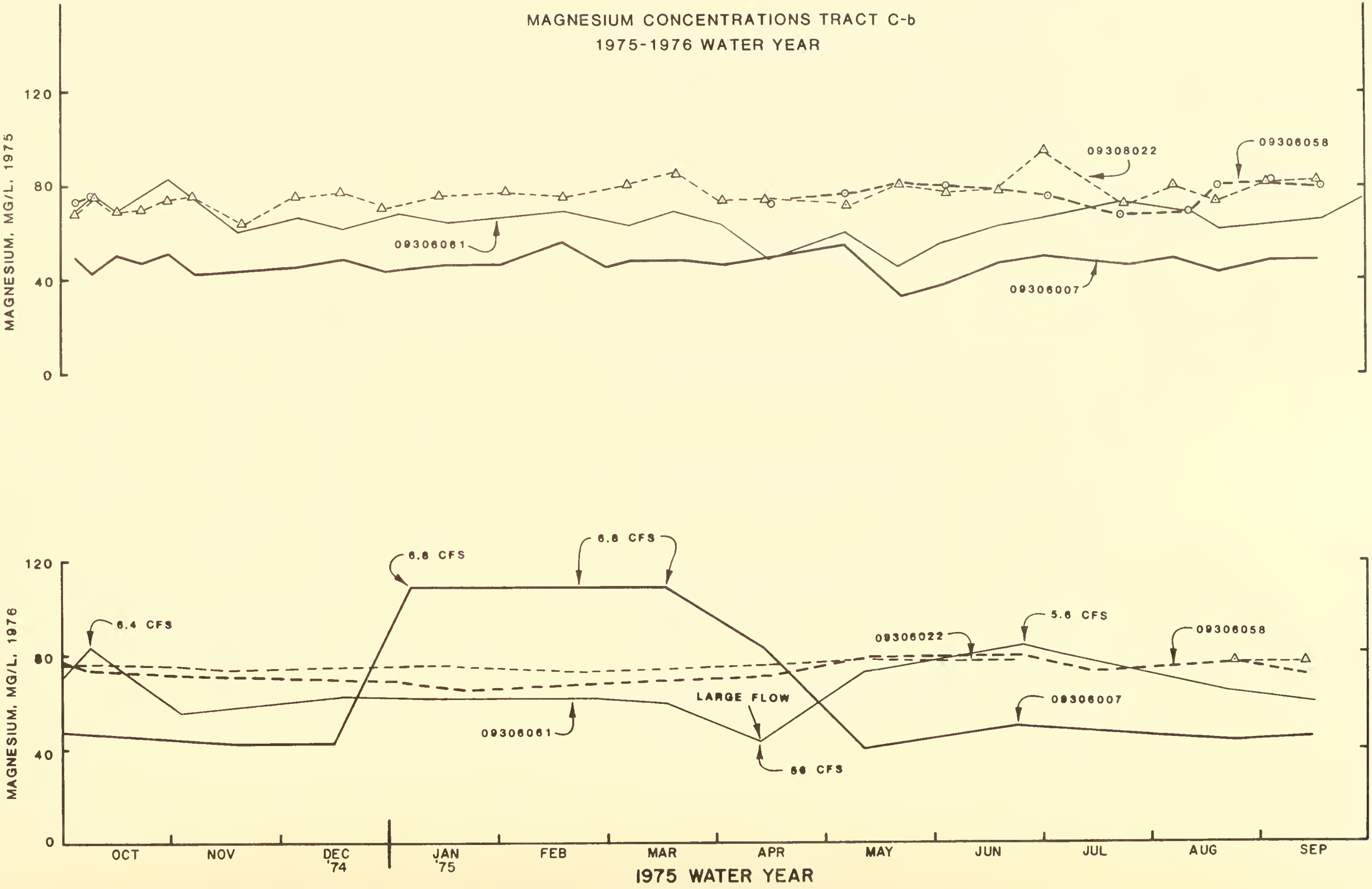

MAGNESIUM CONCENTRATIONS TRACT C-b
1975-1976 WATER YEAR

FIGURE 3-28

SODIUM CONCENTRATIONS TRACT C-b
1975-1976 WATER YEAR

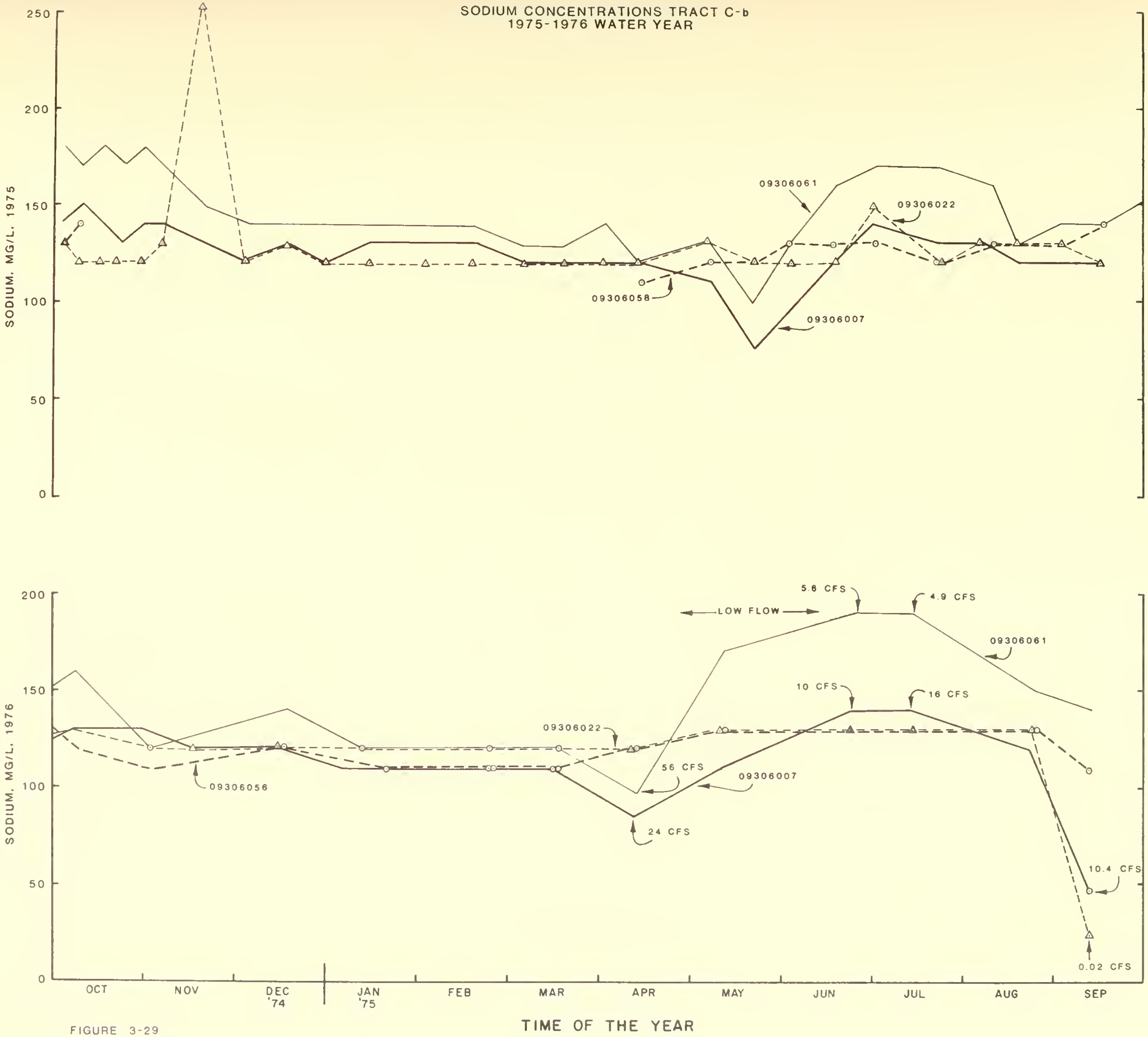


FIGURE 3-29

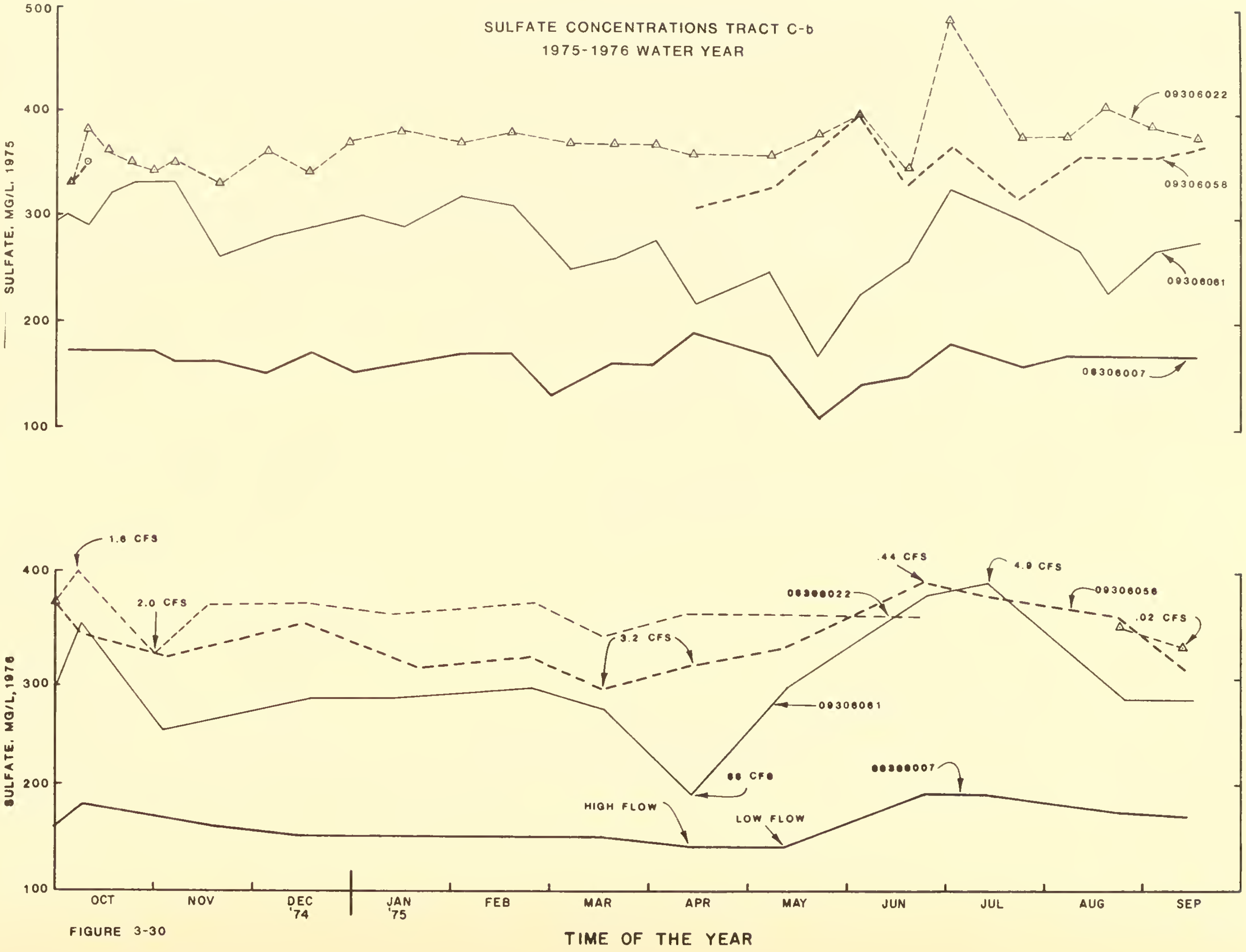

SULFATE CONCENTRATIONS TRACT C-b
1975-1976 WATER YEAR

FIGURE 3-30

BICARBONATE CONCENTRATIONS TRACT C-b
1975-1976 WATER YEAR

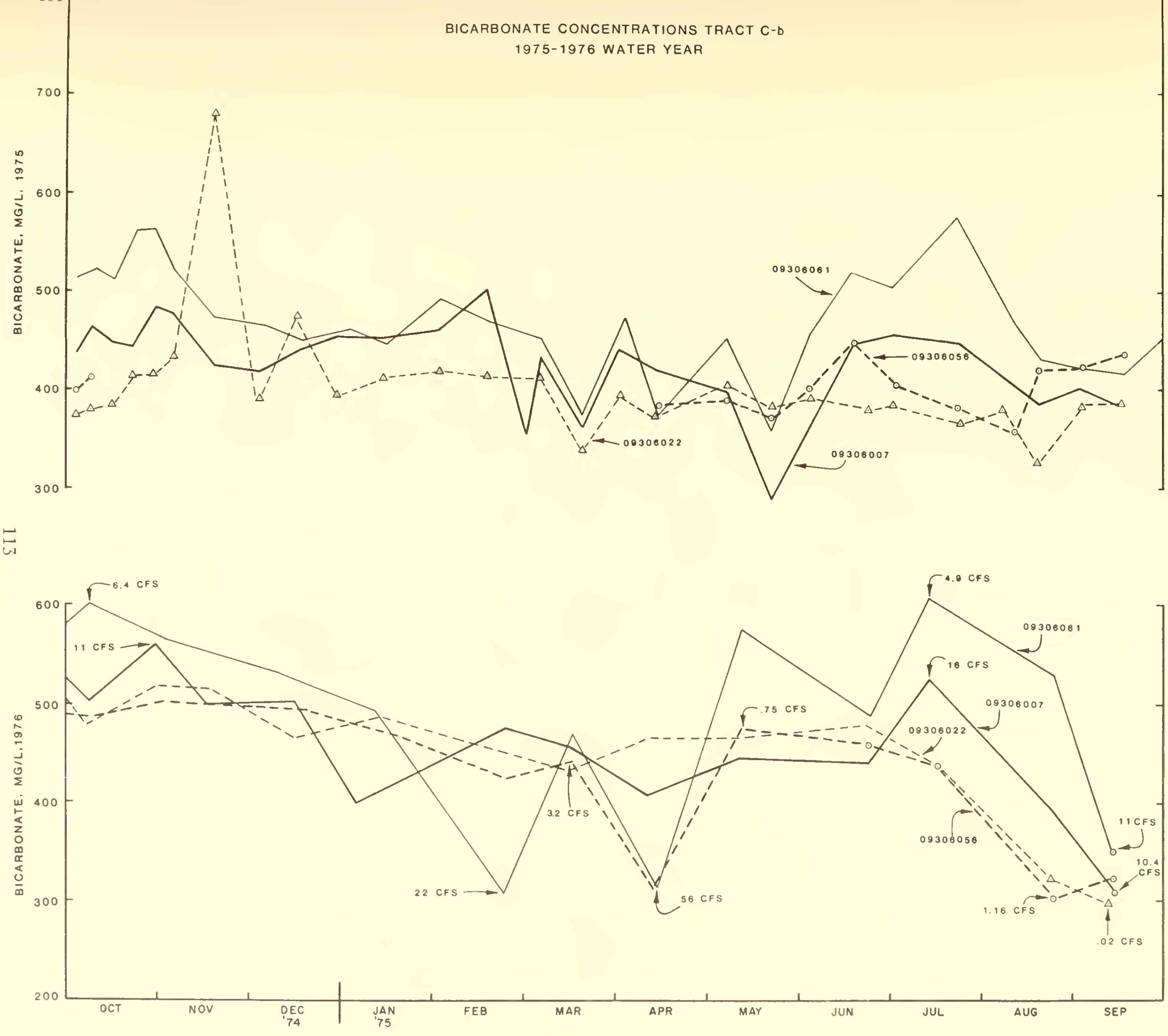


FIGURE 3-31

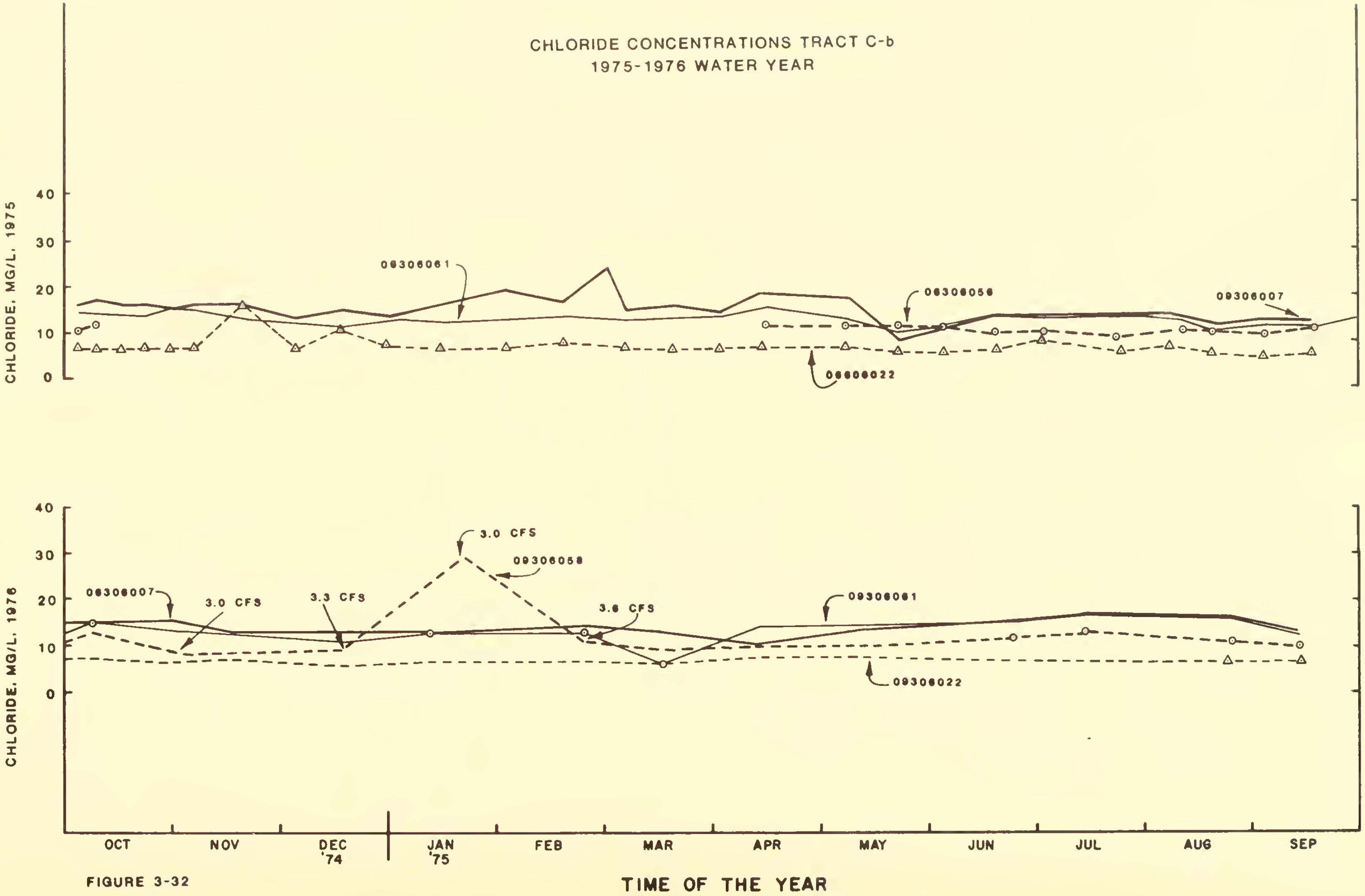

CHLORIDE CONCENTRATIONS TRACT C-b
1975-1976 WATER YEAR
CHLORIDE, MG/L. 1975
40
30
20
10
0
09306061
09306058
09306007
09306022
CHLORIDE, MG/L. 1976
40
30
20
10
0
3.0 CFS
09306058
09306007
3.0 CFS
3.3 CFS
3.6 CFS
09306061
09306022
OCT
NOV
DEC '74
JAN '75
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
TIME OF THE YEAR

FIGURE 3-32

In general, time plots of magnesium concentrations are similar to those of calcium in that they are fairly constant throughout the year and from station to station (Figure 3-28). However, concentrations in the winter of the 1976 water year at Station 09306007 are inexplicably high, reaching a new maximum in January of 110 mg/1 and repeating this high again in February and March. Instantaneous flow at each occasion was about 8.7 cfs implying this maximum was a function of flow. However, at an instantaneous flow of 5.6 cfs in December 1975 the concentration was 44 mg/1 and at a flow of 9.9 cfs in May 1976, the concentration was 40 mg/1, which contradicts the previous implication. Also, at Station 09306061, new highs (84 mg/1) correspond with low stream flow (6.4 cfs, October 1975 and 5.6 cfs, June 1976) and a new low (44 mg/1) corresponds with high stream flow (56 cfs, April 1976). Mean concentrations of magnesium on the water of the tributaries are higher than those on Piceance Creek and the mean at Station 09306061 is 20 mg/1 higher than the mean of 47 mg/1 at Station 09306007 indicating an increase downstream across the Tract.

Sodium concentrations (Figure 3-29) are fairly steady at all stations from November through April. With the beginning of the irrigation diversions in May, sodium concentrations in the surface waters vary widely. The general increase in concentrations for May, June, July, and August might be attributed to ion exchange in soil and sediment--a common result of irrigation water percolating through the soil. Patterns of the concentrations plotted against time are almost identical for the two years. The mean for 09306007, at 120 mg/1, is 32 mg/1 lower than the mean at 09306061. Except for the West Fork of Stewart Gulch, the means are lower in the tributaries than they are in Station 09306061. Lowest concentrations were on Stewart Gulch with 3.5 mg/1 at 09306025 and 24 mg/1 at 09306022.

Sulfate concentrations (Figure 3-30), like sodium, are fairly constant from November through April, apparently as a result of constant flow, but with the beginning of the irrigation season, they fluctuate widely from one extreme to another. Concentrations are lowest at Piceance Creek near Rio Blanco 09306007, constantly less than 200 mg/1, and highest on Stewart Gulch at 09306022 and 09306025 where they are consistently greater than 320 mg/1. Concentrations in the tributaries are considerably higher than those on Piceance Creek and concentrations increase downstream. The mean at 09306007 is 160 mg/1; that at 09306061 is 290 mg/1.

Bicarbonate concentrations (Figure 3-31) fluctuate widely throughout the year at all stations. The smallest range of values, 265 mg/1, and lowest mean, 485 mg/1, is in Willow Creek. Stewart Gulch has the greatest range, particularly on the West Fork where the minimum is 69 mg/1 and the maximum is 757 mg/1, almost a 700 mg/1 fluctuation. Station 09306061 below the Tract on Piceance Creek has the highest mean, 582 mg/1.

Chloride concentrations, except for the waters of Willow Creek, are fairly constant. Maximum variations from the means occurred during the 1975 water year in Piceance Creek and in the waters of West Stewart Gulch. The maximum deviation was about 8 mg/1 at Station 09306022 in November of 1974. Concentrations were so consistent in 1976 that the range of values was less than 7 mg/1. At 09306058 concentrations on Willow Creek fluctuated widely during the winter of 1975-1976. Concentrations varied from a yearly minimum of 8 mg/1 in November (instantaneous discharge at 3.0 c/s) to a yearly maximum of 29 mg/1 in January (instantaneous discharge at 3.0 c/s). Variation on concentration is shown in Figure 3-32.

Comparison of the ionic concentrations and stream flow particularly on Piceance Creek shows that while a certain constituent may react differently to changes in streamflow, in general the total dissolved solids content of Piceance Creek water varies inversely with the flow rate. During the summer low flow period, there is a general increase in concentrations of constituents. A similar increase is seen in October during which month the lowest flows have been recorded. This can be interpreted as a classic dilution effect--where the base stream flow originates from ground water sources with a high total dissolved solids content. During periods of storm runoff or snow melt, the addition of higher quality runoff water results in a diluting effect and a lowering of concentrations of dissolved solids. The increase in TDS during the irrigation season can also be related to evapotranspiration in the irrigation process and to the leaching of minerals from the fields being irrigated.

The dates of minimum and maximum concentrations for major constituents were examined. At Piceance Creek Stations, 09306007 and 09306061, a preponderance of minimum values occurred on May 22, 1975. At this time, the discharge for that day is not known, but it is suspected of being relatively high. Precipitation records at Tract C-b Air Quality Trailer 023 on May 21, 1975, show precipitation in the amount of 1.22 inches. The number and value of the minimum concentrations suggest appreciable dilution. At Station 09306007, minimums were recorded on May 22, 1975, for specific conductivity, bicarbonate (390 mg/1), magnesium (34 mg/1), sodium (75 mg/1), chloride (19 mg/1), fluoride (0.2 mg/1), sulfate (110 mg/1), manganese (10 mg/1) and, of course, hardness. At Station 09306061 all the above elements except bicarbonate, fluoride, and manganese recorded minimums (magnesium 46 mg/1, sodium 100 mg/1, chloride 11 mg/1, and sulfate 170 mg/1). In contrast, calcium was recorded at its maximum value for the year on this same date. No other maximums were recorded, but high readings for nitrite, nitrate, and iron were obtained. The low readings can be explained by dilution from storm runoff. An explanation for the high calcium reading at Station 09306007 is not apparent. High nitrites and nitrates could be the result of runoff from pastures in which cattle had been grazing.

In 1976, two new minimums were measured at Station 09306061 and five minimums were measured at Station 09306007. New lows for Kjeldahl nitrogen (.22 mg/l), sodium (47 mg/l), and bicarbonate (317 mg/l) were recorded on September 13, 1976; the other two lows were measured in the previous October for ortho-phosphorous (.0 mg/l), and in December for potassium (2.3. mg/l). On September 13, 1976, the average daily stream flow at 09306007 was 10 cfs which is approximately the daily mean over the 1976 water year. The instantaneous flow at the time the sample was taken was 10.4 cfs at 09306007 and on September 14, 1976, at Station 09306061, the instantaneous discharge was 11.0 cfs. It is difficult to put discharge and constituent values in perspective when at equivalent discharge values, water samples on other dates show average values of constituents, e.g., June 24, 1976.

At Station 09306061, new lows for major constituents are scattered throughout the 1976 water year: bicarbonate on February 25th (309 mg/l at 22 cfs), magnesium (44 mg/l), sodium (97 mg/l), and total dissolved solids (584 mg/l) on April 13th (discharge 56 cfs); and calcium (16 mg/l at 5.6 cfs) on June 25th. At the tributary stations, corresponding new minimum or low concentrations were recorded at Station 09306058 on September 14th and April 13th. Instantaneous discharge at 09306058 on September 14th was 1.88 cfs; on April 13th, instantaneous discharge was 3.2 cfs. On sampling dates, maximum instantaneous discharge was 3.6 cfs on February 25th; minimum instantaneous discharge was 0.12 cfs on July 14th. Obviously, factors other than discharge must be included to explain maximums and minimums in constituent values.

A particularly striking example of the effect of rainfall on snow pack and frozen ground and subsequent effects on stream chemistry was recorded on February 10 and 12, 1976. On February 10th, a localized rainstorm and subsequent runoff caused a high discharge for this station of 0.27 cfs at Station 09306025 on the West Fork of Stewart Gulch, resulting in new minimums for nine constituents on February 10th and six new maximums two days later. Refer to Table 3-28.

At this same station, maximum discharges of 0.15 cfs on October 30, 1974, and of 0.13 cfs on November 6, 1974, had established previous minimum concentrations for calcium and total dissolved solids and maximum concentrations for potassium and iron. The minimum readings are more easily explained (e.g., dilution) than the maximums, some of which are probably related to the flushing away of the products of surficial mechanical and chemical weathering on the Glendive soil series which covers the valley floor. This is a good example of a relationship between various elements in the environment. During the preceding months precipitation was either snow, which during the cold months did not provide runoff, or of an insufficient quantity of rain to cause runoff. Thus, with no overland flow to entrain and transport silt and clay-sized particles, to wash

Table 3-28 NEW EXTREME CONCENTRATIONS FOR SELECTED PARAMETERS U.S.G.S. STATION 09306025 WEST FORK STEWART GULCH TRACT C-b COLORADO

Parameter	2/10/76	2/17/76	Previous Extreme @025	Extreme @ all Stations
		New Minimums*		
Silica	2.5	5.4	2.8	2.8
Calcium	17.	28.	48.	48.
Magnesium	3.1	16.	67.	34. @007
Sodium	3.5	24.	110.	75. @007
Bicarbonate	69.	151.	378.	378.
TDS	74.	239.	782.	502. @007
Specific Cond.	110.	360.	1160.	--
Sulfate	4.4	70.	340.	110. @007
Chloride	2.0	5.7	6.5	5.8 @022
		New Maximums*		
Iron	210. µg/l	230. µg/l	220. µg/l	1200. µg/l @022
Aluminum	50. µg/l	110. µg/l	--	--
Potassium	46.	12.	9.8	19. @007
Kjeldahl Nitrogen	1.4	2.0	1.3	4.0 @007 & 061
Ortho-phosphorus	.14	.26	.04	.18 @022
Color	45. PCU	130. PCU	45. PCU	30.PCU @061
Dissolved Oxygen	15.6	11.0	13.5	--

*mg/l unless noted.

away chemical patinas, or take into solution products of weathering and vegetative decomposition as they formed, there was a build up of fine materials and soluble chemical compounds on the surface of the soils.

Thus, when a combination of weather conditions provided (1) an air temperature greater than freezing to initiate snowmelt and (2)a rainfall precipitation event to enhance snowmelt and contribute to the local supply of water, there was sufficient water to cause overland flow. The previous cold weather had been sufficient to freeze the ground and, except for a few inches below the surface, the soil could be considered impermeable and would not allow infiltration of this runoff. With the infiltration reduced or eliminated, the only release was overland flow to the established stream channel.

During overland flow, the fine clay and silt particles were entrained and chemical compounds were taken into solution. The sediment would also serve to cloud and color the water. Chemical compounds and patinas that formed on or near the soil's surface would likely be oxides of the most dominant and reactive elements in the soil. "Substances which are removed in solution from the (weathered) rocks include minerals originally present, and the products from hydrolysis, oxidization, carbonation, and less common chemical reactions (Keller 1968)."

The Glendive sandy loam has the highest iron and potassium content of all the soils mapped and analyzed in the Tract C-b study area. It also has a high phosphorus content. Sodium, sulfate, and chloride are in the high range but the exchange capacity of the soil is low. Percolation through the soil would have been limited by the shallow depth of the thawed zone thus reducing the possibility of taking the major ions and silica into solution.

Chemical analysis of two samples of snow obtained on the C-b Tract show a Kjeldahl nitrogen content of 1.3 and 1.8 mg/1. The snowmelt could have accounted for the increase in the total Kjeldahl nitrogen content of the water and been responsible for the maximum reading.

The ion content of the runoff would resemble that of precipitation, rather than that of the typical flow in West Fork of Stewart Gulch which is attributed to seeps of ground water. The entrainment of clay-sized particles and consequent solution of surface weathering products could contribute to the higher aluminum, iron, and potassium concentrations. Cold water temperatures and turbulence in the overland flow and in the channel of West Stewart Gulch would charge the runoff with a high dissolved oxygen content.

The above speculation includes circumstances involving climatic processes to initiate the phenomenon. Hydrogeomorphic processes acting on a soil that had been subjected to physical and chemical weathering created the situation to provide the new extremes in water chemistry in this microenvironmental situation.

Maximum readings are more scattered, but on June 26, 1974, prior to institution of the baseline, maximum readings were obtained at Station 09306007 for specific conductivity and at Station 09306061 for specific conductivity, potassium (6.4 mg/l), chloride (16 mg/l), sodium (200 mg/l), and manganese (190 mg/l). The lowest flow of the year was recorded on June 27, 1974 at Station 09306061.

On July 2 and 11, 1974, maximum values were recorded at both Piceance Creek stations for bicarbonate, magnesium, sodium, sulfate, and hardness. Maximums were also recorded for nitrate, nitrite, phosphate, and manganese at the upstream Station 09306007. These maximum values occurred at the end of an eight-week period of constant low flow. Thus, it is not surprising that there was an increase in concentration of the more soluble ions. The nitrite, nitrate, and phosphate maximums could be attributed to agricultural sources, e.g., fertilization of hay meadows with manure.

New maximums at Piceance Creek stations were a rarity in 1976. At Station 09306007, a new maximum for magnesium (110 mg/l) was obtained on January 6th and was equaled the following two months. Instantaneous discharges at each sampling approximated 8.7 cfs as previously discussed. At Station 09306061, downstream from the Tract, a new maximum for color was obtained on April 13th. A new maximum sulfate concentration (390 mg/l) was reported on July 14th, a year after the previous maximum was recorded. Instantaneous discharge on July 14th was 4.9 cfs, the lowest of the recorded instantaneous discharges for this station.

The above discussion has been directed toward major ions and some extremes in other constituents. In the following Tables (3-29 through 3-34) the parameters measured are listed by surface water gauging station. Values are given for the range in concentration of the number of samples, the mean value, and the standard deviation. For those constituents where concentrations are reported as being "less than" a certain value the mean is reported as being less than the calculated value and no standard deviation is calculated. No mean is calculated for constituents where only two samples are available. Minor trace elements, pesticides, and radioactive analyses were made on a quarterly basis and are reported in the next section.

3.1.5.5.3 Quarterly Data and Trace Elements

Several of the trace elements being monitored have been found only in very low concentrations near the lower limit of analytical detectability. On the basis of this information, at the end of the first year of baseline, sampling frequency for these trace elements was changed to quarterly. Monthly sampling was continued for the trace elements shown in Table 3-31; those monitored on a quarterly basis are shown in Table 3-32, the Chlorinated Hydrocarbons, Table 3-33, and the Radioactivity Analysis, Table 3-34. No visible

Table 3-29
SURFACE WATER QUALITY PARAMETERS
(Units MGL Unless Noted)

U.S.G.S. STATION NUMBER		SPECIFIC CONDUCTANCE UMHOS	pH	TOTAL DISSOLVED SOLIDS	DISSOLVED OXYGEN	ALKALINITY as $CaCO_3$	HARDNESS (Ca, Mg)	FECAL COLIFORM PER 100 ml	STREPTOCOCCI PER 100 ml	SUSPENDED ORGANIC CARBON	DISSOLVED ORGANIC CARBON	COLOR (PLU)	OIL AND GREASE	TURBIDITY (JTU)
	Range	850-1540	6.9-9.0	502-829	6.9-12.6	280-506	290-420	B4, B45	B84, B85	.5-3.6	4.5-38	1-30	0-10	0-480
	No.	57	55	56	53	56	57	2	2	7	9	12	24	20
09306007	Mean	1092	8.3	692	9.9	422	362			1.9	14.3	9	2.2	55
	Std.Dev.	127	.3	69	1.3	50	29			1.5	11.4	9	2.7	
	Range	750-1750	7.2-8.8	865-1160	7.2-13.8	350-641	460-610	<1, 120	B20, 70	.2-1.7	3.8-25	0-5	0-9	0-30
	No.	42	42	42	40	42	42	3	3	7	8	12	20	20
09306022	Mean	1357	8.2	936	10.0	403	548			.7	10.7	2	3	11
	Std.Dev.	142	.3	62	1.3	54	25			.5	9.5	1.3	3	9
	Range	1100-1590	7.8-9.4	778-1150	7.0-12.7	267-468	460-610	<1, B34	B34, 140	.2-2.2	2.6-22	0-9	0-3	
	No.	38	38	39	37	39	39	2	2	5	8	22	16	
09306058	Mean	1360	8.3	926	9.8	402	543			1.24	6.6	4	1	
	Std.Dev.	93	.3	74	1.5	45	28			.8	6.4	2.5	1	
	Range	940-1660	7.5-9.2	584-1090	6.4-16.0	257-566	340-570	B22	120, B360	.8-4.4	3.8-11	0-40	0-9	
	No.	54	53	55	50	55	55	1	2	4	8	28	21	
09306061	Mean	1348	8.2	902	9.9	465	470			2.5	7.0	9	3	
	Std.Dev.	171	.3	114	1.9	60	52			1.5	2.5	10	3	
	Range	510		306		154	170					65	0	
	No.	1		1		1	1					1	1	
09306015	Mean													
(1976 only)	Std.Dev.													
	Range	110-2070	7.4-8.9	74-1450	5.0-15.6	57-621	55-740	B4, 160	300, 350	.4-3.5	1.0-28	10-130	0-2	
	No.	39	36	39	34	39	39	2	2	4	7	8	10	
09306025	Mean	1518	8.4	1065	9.0	412	596			2.0	.2	37	1.2	
	Std.Dev.	344	.3	240	2.0	95	134			1.7	10.8	39	.6	
	Range	160,380	7.9,8.3	117,239		48,63	48,87	<1	400	1.3, 30	25,27	35,40	0,1	
	No.	2	2	2		2	2	1	1	2	2	2	2	
09306033	Mean	270	8.1	178		56	68			16	26	38	.5	
(1976 only)	Std.Dev.													
	Range	220		176	10.3	133	76						4	1100
	No.	1		1	1	1	1						1	1
09306050	Mean													
(1975 only)	Std.Dev.													
	Range	1220	8.5	814	10.0	402	270						0	200
	No.	1	1	1	1	1	1						1	1
09306039	Mean													
(1975 only)	Std.Dev.													
	Range	300		223	11.9	169	78						5	960
	No.	1		1	1	1	1						1	1
09306052	Mean													
(1975 only)	Std.Dev.													

Table 3-30
MAJOR CONSTITUENTS - SURFACE WATER

		NH_4 as N	HCO_3	Ca	CO_3	Cl	*	NO_2	Mg	NO_3	PO_4 as P	K	Na	SiO_2	SO_4	S
	Range	.00-.13	317-617	51-79	0-32	9-24	.22-4.0	.00-.13	34-110	.22-3.70	.00-.11	2.3-19	47-160	3.4-18	110-200	.0-.9
	No.	31	56	57	45	57	30	20	57	20	57	57	57	57	57	25
09306007	Mean	.04	513	69	1.4	15	.76	.54	46	1.44	.03	3.6	122	15	164	.2
	Std.Dev.	.04	63	6	5.3	2.4	.74	.03	5	.9	.05	2.2	20	2	17	.2
	Range	00-.09	427-782	73-99	0-38	5.8-16	.02-3.5	.00-.13	64- 95	.22-8.4	.02-3.5	1.1-2.5	120-250	11-17	320-490	.0-.7
	No.	30	42	42	32	42	27	20	42	20	42	42	42	42	42	20
09306022	Mean	.02	489	93	1.5	7.2	.46	.02	76	6.7	.01	1.6	124	15	368	.13
	Std.Dev.	.02	66	5	-	1.6	.63	.03	5	1.8	.01	.4	26	.8	28	.16
	Range	.00-.11	305-570	64-100	0-46	8.2-29	.12-3.5	.00-.03	67- 87	.62-2.1	.00-.17	1.1-5.0	110-180	12-18	290-500	.0-.3
	No.	19	39	39	35	39	17	11	39	11	39	39	39	39	39	15
09306058	Mean	.02	485	92	3	11.5	.64	.02	76	1.33	.02	2.2	128	15	356	.1
	Std.Dev.	.02	59	8	-	3.1	.91	.01	5	1.49	.03	.76	13	1.4	40	.1
	Range	.00-.09	309-690	16-88	0-85	11-16	.21-4.0	.00-.03	44- 88	.21-3.5	.00-.08	1.2-6.4	97-200	12-20	170-390	.0-.5
	No.	29	55	55	44	55	30	21	55	22	55	55	55	55	55	24
09306061	Mean	.03	561	78	3	14	.83	.02	67	2.1	.03	3.5	150	17	290	.2
	Std.Dev.	.02	83	6	14	1.4	.92	.02	10	1.0	.02	.9	25	2.0	47	.2
	Range	.21	188	33	0	5.7	3.8	.00-.03	20	.00-5.7	.19	11	37	5.6	98	.3
	No.	1	1	1	1	1	1	10	1	10	1	1	1	1	1	1
09306015	Mean							.02		.72						
1976 only	Std.Dev.							.02		1.76						
	Range	.00-.11	69-757	17-130	0-37	2.0-29	.12-2.0		3.1-120		.00-.26	.9-12	3.5-220	2.5-18	4.4-590	.0-.2
	No.	15	41	41	30	39	15		41		39	41	41	41	39	10
09306025	Mean	.03	496	85	2	10	.67		92		.02	3.4	148	12.9	463	.1
	Std.Dev.	.04	113	20	7	4	.51		22		.05	2.2	36	4.0	112	.1
	Range	.04	59, 77	16,26	0,0	7.8,16	.71		2.0,5.4		.01-.04	1.3,1.7	20, 43	4.1,5.8	27,100	.2, .5
	No.	1	2	2	2	2	1		2		2	2	2	2	2	2
09306033	Mean		68	21	0	11.9			3.7		.2	1.5	32	5.0	64	.4
1976 only	Std.Dev.															
	Range		162	23	0	3.2	15	.30	4.4	.84	.30		43	84	10	
	No.		1	1	1	1	1	1	1	1	1		1	1	1	
09306050	Mean															
1975 only	Std.Dev.															
	Range	.18	449	50	20	30	.50	.03	34	.97	.02	1.3	200	17	230	.2
	No.	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
09306039	Mean															
1975 only	Std.Dev.															
	Range		206	23	0	13	23	.23	5	.58	.50		55	8.3	11	
	No.		1	1	1	1	1	1	1	1	1		1	1	1	
09306052	Mean															
1975 only	Std.Dev.															

* Kjeldahl Nitrogen

Table 3-31 IMPORTANT TRACE ELEMENTS - SURFACE WATER

(UGL Except as Noted)

		Al	As	Ba	B	Cd	Cr	Cn*	Cu	F*	Fe	Pb	Mn	Hg	Li	Se	Sr*	Zn
	Range	10-40	0-5	0-300	110-330	0-<15	0-90	.00-.02	0-12	.2-1.3	0-390	0-<20	10-230	0-.8	0-20	0-2	1.2-1.4	0-60
	No.	9	51	49	56	45	8	25	45	57	58	48	44	46	48	46	9	48
09306007	Mean	22	2.4	<100	209	<.8	<7	.002	<2.5	.9	62	<4	46	.06	9	.9	1.4	<17.35
	Std. Dev.	11	1.0	-	45	-	-	-	-	.2	79	-	105	-	9	.5	.07	-
	Range	0-40	0-4	0-<200	30-530	0-3	0-20	.00-.02	0-8	.1-3.3	0-1200	0-7	0-57	0-.4	0-40	0-2	2.6-3.3	0-370
	No.	7	40	30	42	30	20	20	30	42	40	30	30	30	30	30	7	30
09306022	Mean	20	1	<72	108	<1	<4	.00	2	.3	73	<3	<10	<.1	<8	1.0	2.8	31
	Std. Dev.	12.9	.9	-	84	-	-	.01	2	.5	-	-	-	-	-	.4	.2	67
	Range	0-40	0-4	0-200	70-2800	0-6	0-40	.0-.01	0-17	.3-1.3	10-150	0-<20	0-50	0-.2	0-20	0-2	2.7-2.9	0-40
	No.	5	36	30	36	30	5	16	30	39	38	30	28	31	30	31	5	30
09306058	Mean	16	1.1	<.55	210	<1	<2	.001	<3	.4	33	<3	14	.05	6	1	2.8	12
	Std. Dev.	17	.9	-	-	-	-	-	-	.2	29	-	13	-	5	.4	.01	12
	Range	0-30	0-6	0-<200	130-470	0-2	0-40	.00-.03	0-20	.3-1.5	0-880	0-<20	0-190	0-<.1	0-20	0-2	2.1-2.3	0-50
	No.	5	52	41	52	44	20	21	41	55	54	41	49	42	41	42	5	41
09306061	Mean	12	2.3	<65	214	<1	<4	.00	<3	.9	<68	<3	66	<.1	6	1	2.2	<16
	Std. Dev.	11	1.3	-	-	-	-	.01	-	.2	-	-	52	-	6	.4	.01	-
	Range	30	3	200	130	1	0	.03	5	.1	90			.1		0	.7	10
	No.	1	1	1	1	1	1	1	1	1	1			1		1	1	1
09306015 (1976 Only)	Mean	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Std. Dev.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Range	0-110	0-3	0-200	40-160	0-2	0-20	.00-.01	0-8	0-1.2	0-230	0-20	0-20	0-.9	0-20	0-5	.2-3.2	0-40
	No.	5	38	29	37	29	10	10	29	39	41	32	32	30	20	30	5	29
09306025	Mean	42	1.2	<60	104	<1	4	.002	<3	.2	70	<6	6	.1	6	.4	1.8	<15
	Std. Dev.	42	.9	-	27	-	7	-		.2	61	-	7	.2	6	1.0	1.4	-
	Range	50,110	1,3	0,100	40,110	1,1	0,20	.00,3.0	7,8	.2,.3	30,170	2,4		.0,.0	0,10	1,2	.16,.23	0,10
	No.	2	2	2	2	2	2	2	2	2	2	3		2	2	2	2	2
09306033 (1976 Only)	Mean	80	2	50	75	1	10	1.5	8	.2	100			.0	5	2	.20	5
	Std. Dev.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Range				110			0.0		2.4								
	No.				1			1		1								
09306050 (1975 Only)	Mean				-			-		-								
	Std. Dev.				-			-		-								
	Range	140	7	180	150	<20	<6	100	3	5.2	140	<6	5	<.1	20	4		<20
	No.	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		1
09306039 (1975 Only)	Mean	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-
	Std. Dev.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-
	Range				170			0.0		3.5								
	No.				1			1		1								
09306052 (1975 Only)	Mean				-			-		-								
	Std. Dev.				-			-		-								

*MGL

QUARTERLY ANALYSIS

Table 3-32 MINOR TRACE ELEMENTS - SURFACE WATER

All ug/1

		Al	Ba	Be	Bi	B	Cr	Co	Ga	Ge	Fe	Pb	Li	Mn	Mo	Ni	Ag	Sr	Sn	Ti	V	Zn	Zr
09306007	Range	10-45	100	<7	<2.5	140-200	<20	<20	<8	<30	10-50	<20	10-20	30-<150	0-20	<20	<3	810-2300	<25	<3-25	<20	0-60	<40
	No.	8	4	7	7	4	4	7	7	7	4	4	4	4	8	7	7	8	7	7	7	4	3
	Mean	89	100	<3	<12	160	<14	<10	<4	<12	30	<12	18	75	14	<10	<2	1450	<12	<8	<9	18	<35
	Std. Dev.	150	0			30					16		5		6			450				29	
09306022	Range	10-1300	0-60	<8	<30	60-80	<20	<20	<8	<30	<20-60	<20	5-10	<20	<2-15	<20	<3	1300-2900	<20	<3-50	<20	0-10	<40
	No.		4	6	6	4	4	6	6	6	4	4	4	4	7	6	7	7	6	6	6	4	3
	Mean		4.5	<4	<15	70	<16	<13	<5	<15	<30	<15	9	<18	<8	<12	<1	2300	<14	<16	<10	5	<36
	Std. Dev.		30			8							2					500				6	
09306015	Range	40	100	<3	<10	60	<10	<10	<5	<10	50	<10	10	50	7	<10	<2	1400	<12	<8	<8	80	<30
	No.	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		
09306025	Range	0-680	0,60	<10	<30	90,100	0-<20	<20	<10	<30	60,280	0-<20	10-40	10,60	2-10	<20	<3	2300-3200	<20	<4-20	<20	10,260	<40
	No.	4	2	3	3	2	5	3	3	3	2	5	5	2	4	3	3	4	3	3	3	2	1
	Mean	190	30	<6	<18	95	<8	<16	<7	<17	170	<13	20	35	<6	<11	<2	3000	<14	<11	<11	135	
	Std. Dev.	330											12					450					
09306033	Range	110,160	100,100	<1	<4	30,110	<4,20	<4	<2	<5	130,170	2,<4	0,0	2,20	1,4	<4	<1	160,-220	<5	8	6	0,10	<10
	No.	2	2	1	1	2	2	1	1	1	2	2	2	2	2	1	1	2	1	1	1	2	1
	Mean	135	100			70	<12				150	<3	0	11	2			190				5	
09306039	Range	140	-	<2	<6	-	-	<6	<3	<6	-	-	-	-	10	<4	0	3300	<6	6	<3	-	-
	No.	1	-	1	1	-	-	1	1	1	-	-	-	-	1	1	1	1	1	1	1	-	-
09306058	Range	20-50	0-70	<8	<25	80-100	<20	<20	<9	<30	10-60	<20	0-20	<20-30	2-20	<20	<3	1800-3000	<30	<20	<20	0-10	<40
	No.	7	4	6	6	4	4	6	6	6	4	4	4	4	7	6	6	7	6	5	6	4	3
	Mean	31	50	<4	<16	85	<15	<15	<6	<17	35	<14	10	<22	<11	<13	<2	2450	<17	<9	<12	2.5	<40
	Std. Dev.	11	34			10					21		8					400				5	
09306061	Range	0-60	0-100	<2-<10	<4-<30	120-180	<20	<20	<10	<30	20-80	<20	10-20	20-120	4-20	<20	<3	1200-2400	<30	<20	<20	0-10	<40
	No.	8	4	6	6	6	6	6	6	6	4	4	4	4	7	6	6	8	6	6	6	4	3
	Mean	25	65	<4	<15	155	<8	<12	<5	<15	42	<14	12	50	13	<12	<1	1950	<15	<8	<11	5	<40
	Std. Dev.	20	44			30					26		5	45	7			400				6	

Table 3-33 CHLORINATED HYDROCARBONS AND CARBONATE PESTICIDES IN SURFACE WATER, TRACT C-b

		TOTAL ALDRIN (UGL)	TOTAL CHLORDANE (UGL)	TOTAL DDD (UGL)	TOTAL DDE (UGL)	TOTAL DDT (UGL)	TOTAL DIAZINON (UGL)	TOTAL DIELDRIN (UGL)	TOTAL ENDRIN (UGL)	TOTAL HEPTACHLOR (UGL)	TOTAL HEPTACHLOR EPOXIDE (UGL)	TOTAL LINDANE (UGL)	TOTAL MALATHION (UGL)
09306007	Range												
	No.												
09306022	Range												
	No.												
09306025	Range												
	No.												
09306039	Range												
	No.												
09306058	Range												
	No.												
09306061	Range				.00-.01								
	No.				6								
	Mean				.002								
	Std. Dev.				.004								

		METHYL PARATHION (UGL)	TOTAL PARATHION (UGL)	TOTAL PCB (UGL)	TOTAL TOXAPHENE (UGL)	TOTAL 2,4-D (UGL)	TOTAL 2,4,5-T (UGL)	TOTAL SILVEX (UGL)	TOTAL ETHION (UGL)	TOTAL TRITHION (UGL)
09306007	Range									
	No.									
09306022	Range									
	No.									
09306025	Range									
	No.									
09306039	Range									
	No.									
09306058	Range									
	No.									
09306061	Range									
	No.									

Quarterly analysis of water samples for all these constituents were zero except for Total DDE at Station 09306061 on December 17, 1975 when water samples indicated .01 UGL Total DDE.

TABLE 3-34

RESIDUE AND RADIOACTIVITY ANALYSIS QUARTERLY SAMPLES
Tract C-b

		TOTAL FILTRABLE RESIDUE (MGL)	TOTAL NON-FILTRABLE RESIDUE (MGL)	DISSOLVED GROSS ALPHA AS U-NAT. (UGL)	SUSPENDED GROSS ALPHA AS U-NAT. (UGL)	DISSOLVED GROSS BETA AS CS-137 (PCL)	SUSPENDED GROSS BETA AS CS-137 (PCL)	DISSOLVED GROSS BETA AS SR90/Y90 (PCL)	SUSPENDED GROSS BETA AS SR90/Y90 (PCL)	DISSOLVE RA-226 (RADON METHOD) (PCL)	DISSOLVED URANIUM DIRECT FLUORO-METRIC (PCL)
09306007	Range	450-770	22-200	6.8-18	.9-7.8	2.2-40	.9-7.8	1.7-32	.8-6.4	.04-.08	2.0, 2.2
	No.	4	4	7	7	4	4	4	7	2	2
	Mean	650	86	<11.6	3.4	13.8	3.6	8.0	2.7	.06	2.1
	Std.Dev.	140	78		2.2	17.6	3.0	10.7	1.8		
09306022	Range	960-1000	1-55	<11-14	<.4-4.3	<2.9-4.6	<.4-2.4	<2.3-3.7	<.4-2.8	.06,.07	1.9, 2.1
	No.	4	4	7	7	4	4	7	7	2	2
	Mean	980	22	<12	<1.5	<3.6	<1.2	<3	<1.5	.065	2.0
	Std.Dev.	20	26								
09306025	Range	990	5	<12, <14	<.4, <.4	11	<.4	2.7, 9	<.4, .6	<.1**	2.3
	No.	1	1	2	2	1	1	2	2		
09306033	Range	-	-	<3, 6.1	5.5, 1100*	5.2, 7.4	7.9, 520*	4.1, 6.1	6.3, 440*	.15	1.0
	No.			2	2	2	2	2	2	1	1
09306039	Range	820	520	24	18	4.1	27	3.3	23	.09	
	No.	1	1	1	1	1	1	1	1	1	
09306058	Range	960, 1200	<1, 11	<8.3-23	<.4-9.6	5.1, 26	<.4, .6	3.8-31	<.4-4.9	.05	1.7, 1.6
	No.	2	2	5	5	2	2	5	5	1	2
	Mean	1080	<6	<14	<4	16		13	< 2.5		
	Std.Dev.							12			
09306061	Range	830-2000	1-260	<25	<.4-13	6.1-43	<.4-12	3.1-34	<.4-10	.05, .07	2.0, 2.6
	No.	4	4	7	7	4	4	7	7	2	2
	Mean	1130	110	<14	<6.3	16.8	<5	9.6	<4	.06	2.3
	Std.Dev.	580	125			17.5		11			

*Heavy sediment load. Value must be reduced by the size of the sample.
**Planchet count instead of Radon Method.

trends can be seen with respect to geographic distribution, land use, or origin of the stream. There is a tendency for some constituents, to increase downstream, e.g., copper, aluminum, and zinc increase downstream toward the White River. Fluoride levels increase downstream in Piceance Creek.

A quarterly analysis is made for chlorinated hydrocarbons, and carbonate pesticides, and for some herbicides Table 3-33, and for radioactivity Table 3-34. At only one station was any trace of a pesticide reported. This was a reading for DDE of 0.01 ug/1 for Station 09306061 on December 17, 1975.

Sampling for radioactivity was set up so that water would be sampled for gross alpha and gross beta at the four major gauging stations on a quarterly basis and at minor stations on quarterly basis provided flow was coincident with the sampling period or on an opportunistic basis. If dissolved gross alpha activity was greater than four picocuries per liter (pc/1), then the sample was analyzed for radium 226 and natural uranium. If gross beta activity was greater than 100 pc/1, the sample was analyzed for strontium 90 and cesium 137. Table 3-34 presents the mean values for the quarterly samples for filterable residue, non filterable residue, and radioactive measurements. Gross alpha is presented as ug/1 for an equivalent mass of natural uranium. That is, the activity count of the undifferentiated alpha-emitters is calibrated against the emission potential of a standard isotope of natural uranium so that

measured count = X ug/1 Uranium Natural.

Similarly gross beta activity is calibrated against two isotopes, one a combination of strontium 90 and yttrium 90, the other an isotope of cesium 137. In those cases where dissolved gross alpha exceeded the maximum allowable count of four pc/1 dissolved radium 226 is reported. Dissolved beta never reached the maximum and therefore no analyses were made for strontium 90 and cesium 137.

Dissolved radium analyses were obtained from samples taken June 4, 1975, at stations 09306007, 09306022, and 09306061; from samples taken March 16-17, 1976, at stations 09306007 and 09306058; from samples taken December 4-6, 1974 at stations 09306022, 09306039, and 09306061; and from samples taken July 31, 1976 at station 09306033. All of the radium 226 measurements are well under the desirable maximum limit of <1 pcl.

Methylene blue active substances, typically phosphate detergents, were measured in December 1975 and February 1976. The maximum quantity analyzed was 2.0 mg/1 at stations 09306022 and 09306061.

Table 3-35 presents the Public Health Service standards, generalized effects of quantities in excess of the standards and the mean and maximum values encountered during the baseline period. Colorado proposed

Table 3-35

COMPARISON OF PUBLIC HEALTH STANDARDS, COLORADO PROPOSED STANDARDS AND CONCENTRATIONS IN THE SURFACE WATER

Trace Element or Compound	Health or Aesthetic Effect	1962 USPHS Drinking Water Standard Limit mg/1	Proposed Colorado Water Quality Standards (mg/1)			Max. Level on C-b Tract and Station Number**	
			Aquatic Life	AG	Municipal Water Supply	Maximum mg/1	Station No.
Ammonia (as N)		0.5 (As N)	0.02 un-ionized	--	0.5	.18	033
Arsenic (As)	Serious systemic poison--100 mg usually causes severe poisoning, is cumulative, and may cause chronic effects. Late evidence indicates tiny amounts may be beneficial.	0.01 0.05	.05	.1	.01	.006	061
Barium (Ba)	Fatal dose is 550-600 mg as the chloride; muscle (including heart) stimulant.	1.0				.3	007
Beryllium (Be)	Poisonous in some of its salts in occupational exposure.	None	.011	.1	.1	<.010	025
Bismuth (Bi)	A heavy metal in the arsenic family--avoid in water supplies	None	.0004	.01	.01	<.030	022 025
Boron (B)	Ingestion of large amounts can affect central nervous system, and protracted ingestion can cause borism.	1.0	--	0.75	--	2.800	058
Cadmium (Cd)	13-15 ppm in food has caused illness.	0.01				<.02	039
Chloride (Cl^-)	Limit set for taste reasons	250.	--	--	250.	30.	039
Chromium (Cr^{+6})	Limit provides a safety factor. Carcinogenic when inhaled.	0.05	0.3	0.1	0.05	.09	007
Cobalt (Co)	Beneficial in small amounts; about 7 mg/day.	None				<.020	Several
Copper (Cu)	Body needs copper at level of about a mg/day for adults; not a health hazard except when large amounts are ingested.	1.0				.020	061
Cyanide (CN^-)	Rapid fatal poison, but limit set provides safety factor of about 100.	0.1 0.2	0.005	0.2 stock	0.2	0.1	039
Fluoride (F^-)	Beneficial in small amounts; above 2,250 mg dose can cause death.	0.7-1.2 1.4-2.4	--	2.0	2.0*	5.2	039
Iron (Fe)		0.3	0.5	--	0.3	1.2	022
Lead (Pb)	Serious, cumulative body poison.	0.05	0.004	0.1 stock 5.0	0.05	.020	025

* Fluoride limits vary depending upon the temperature.
** Only last 3 digits of USGS station number used.

Table 3-33 (Cont'd)

Trace Element or Compound	Health or Aesthetic Effect	1962 USPHS Drinking Water Standard Limit mg/1	Proposed Colorado Water Quality Standards (mg/1)			Max. Level on C-b Tract and Station Number**	
			Aquatic Life	AG	Municipal Water Supply	Maximum mg/1	Station No.
Magnesium (Mg)		125.	--	--	125.	120.	025
Manganese (Mn)		0.05	1.0	0.2	0.05	.230	007
Mercury (Hg)	Continued ingestion or large amounts can damage brain and central nervous system.	0.005	0.00005	0.01	0.002	.0009	025
Molybdenum (Mo)	Necessary for plants and ruminants. Excessive intakes may be toxic to higher animals; acute or chronic effects not well known.	None	--	0.5 stock	--	.020	Several
Nickel (Ni)	May cause dermatitis in sensitive people; doses of 30-73 mg of $NiSO_4$+$6H_2O$ have produced toxic effects.	None	0.05	0.1	0.01	<.020	Several
Nitrate (NO_3)	Excessive amounts can cause methemoglobinemia (blue baby) in infants.	45.	6.3		<0.1-127	8.4	022
Nitrites plus nitrates (as N)		10. (as N)	--	100	10	--	--
Selenium (Se)	Toxic to both humans and animals in large amounts. Late research suggests small amounts may be beneficial.	0.01	0.05	0.05 stock	0.01	.005	025
Silver (Ag)	Can produce irreversible, adverse cosmetic changes.	0.05	0.0001	--	0.05	<.003	Several
Sodium (Na)	A beneficial and needed body element, but can be harmful to people with certain diseases.					250.	022
Solids, Total Dissolved		500.				1.450	025
Sulfate (SO_4)	Above 750 mg/1 usually has laxative effects.	230.	--	--	250.	590.	025
Tin (Sn)	Long used in food containers without known harmful effects.	None				<.030	058
Vanadium (V)	Some evidence that vanadium may be beneficial with respect to heart disease.	None				<.020	Several
Zinc (Zn)	Zinc is beneficial in that a child needs 0.3 mg/kg/day; 675-2,280 mg/1 may be an emetic.	5.	0.05	2.0	0.6-5.0	.370	022

** Only last 3 digits of USGS station number used.

Table 3-35 (Cont'd)

Trace Element or Compound	Health or Aesthetic Effect	1962 USPHS Drinking Water Standard Limit mg/1	Proposed Colorado Water Quality Standards (mg/1) Aquatic Life	AG	Municipal	Max. Level on C-b Tract
PESTICIDES						
Aldrin	One or all of these complex organic compounds have severe, acute, adverse health effects when ingested in large amounts. Small amounts accumulate, and long-range effects are generally unknown.	0.017	0.000003			All Values 0 except DDE one time reading of 0.01 mgl.
Chlordane		0.003	0.000050			
DDT		0.042	0.000001			
Dieldrin		0.017	0.000003			
Endrin		0.001	0.000010			
Heptachlor		0.018	0.000010		0.0002	
Heptachlor epoxide		0.018				
Lindane		0.056	0.000010		0.004	
Toxaphene		0.005	0.000010		0.005	
Organic phosphorus plus carbonates, such as Parathion, Malathion, Carbaryl, and others	The organic phosphorus and carbonate pesticides are severe acute poisons affecting the central nervous system; ingestion of small amounts over time can harm the central nervous system.	0.01	varies from 0.00010 for Parathion to 0.000003 for Endosulfan			All Values = 0

Table 3-35 (Cont'd)

Trace Element or Compound	Health or Aesthetic Effect	1962 USPHS Drinking Water Standard Limit mg/1	Proposed Colorado Water Quality Standards (mg/1) Aquatic Life	AG	Municipal	Levels on C-b at U.S.G.S. 09306061 Maximum	Mean
HERBICIDES							
2,4-D	A group having toxic properties of a generally lower order than pesticides. However, they should not be used without great care and should not be found in drinking water.	1.0		0.1		All Values 0	
2,4,5-T		0.1					
Silvex (2,4,5-TP)		0.2					
RADIOACTIVITY (PC_1/1)							
Gross alpha (corrected for Uranium)			15	15	15	<25	<14
Gross beta		1,000	50	50	50	*	
Radium-226		3	5	5	1	.07	.06
Strontium-90		10	2	2	2	Not measured	
Cesium-137			160	160	160	Not measured	
					*Gross Beta		
					as C_s-137	43	16.8
					as Sr 90/γ90	34	9.6

standards or Public Health Service standards are exceeded by boron, chromium, fluoride, manganese, sodium, total dissolved solids, and sulfate. Of these, boron, chromium, and fluoride concentrations exceeded the standards only at the maximum readings obtained during the baseline. The maximum boron concentration of 2.8 mg/l at Station 09306058 and the maximum chromium concentration of .09 mg/l at Station 09306007 were the only readings in excess of the standards. Two fluoride readings exceeded the standards; they were concentrations of 5.2 mg/l at Station 09306039 and 3.3 mg/l at Station 09306007. The reading at 09306039 was the only flow recorded during the baseline.

Standards are also exceeded by manganese, sulfate, and dissolved solids. The manganese limit of .05 is exceeded by the maximum (1.23) at Station 09306007 and the mean (.066) at 09306061. An excess of manganese is not a health problem but can cause staining on clothes and porcelain fixtures.

The standard of 250 mg/l for sulfate is exceeded by the mean concentrations at 09306022 (368 mg/l) and 09306025 (463 mg/l) on Stewart Gulch 09306058 (356 mg/l) on Willow Creek, and 09306061 (290 mg/l) on Piceance Creek above Hunter Creek. The maximum value at Station 09306007 above the Tract is 200 mg/l. It can be seen that tributaries to Piceance Creek are causing the excess in sulfates. The excess is not critical however as the laxative effect of excessive sulfate requires concentrations in excess of 750 mg/l.

The Public Health limit of 500 mg/l for total dissolved solids is exceeded at every major station. Slight excess of TDS can cause taste problems with municipal water and scaling problems with industrial water. The excess of concentrations above the Public Health limit is not critical.

3.1.5.6 Summary

Continuous flow data are available for the 1975 and 1976 water years for surface water gauging stations immediately above and immediately below the C-b Tract. Eleven years of stream flow records at the gauging station eight miles below the Tract indicate a doubling of the base flow and total surface water flow since 1972. If this is also true at the location of the Tract, it is expected that sometime in the future the flow at C-b will return to the pre-1973 average. Any decrease in flow cannot automatically be attributed to oil shale development activities. Consideration of a natural decrease in ground water contributions to the surface flow must be considered and the residual effect of Project Rio Blanco taken into account.

To show the relationships between flow rate and ionic content, several chronological plots of ion concentration were made over the baseline period. Stations 09306007 and 09306061 on Piceance

Creek showed the same general pattern. Little change is seen in the concentrations of the various constituents as a function of flow except at extremes. Some data exhibit a definite increase in the concentrations of dissolved solids at low flows. This could be interpreted as a classic dilution effect (where the base stream flow originates from ground water sources with a high TDS content). During periods of storm runoff or snowmelt, the addition of higher quality runoff water results in a diluting effect and a lower concentration of dissolved solids. The increase in TDS during the irrigation season also can be related to the irrigation process and the leaching from the fields being irrigated. Based on the observed differences between 1975 and 1976 water-year data, the flow in Piceance Creek during relatively wet years is high enough that the dissolved solids concentration remains only slightly affected by irrigation. During low-flow years, these factors will begin to assert themselves.

Major and minor trace elements were measured from samples of surface water collected at various intervals during the two years of baseline. Mean concentrations of manganese, sulfate, and TDS exceed the standards established by the Public Health Service, but none are critical. Standards for boron, chromium, and fluoride have been exceeded by an occasional maximum reading.

Of the pesticides and herbicides tested for in the surface water only DDE was recorded in any amount in six samples--a one time reading of .01 ug/l. Radioactivity in the samples is below health standards as shown in Table 3-35.

Continuous data for the Tract stations is at a premium during the baseline period. Long term data, except for the 12 years of record at the gauge on Piceance Creek at Ryan Creek, 09306200, were not collected for the Piceance Creek or Yellow Creek. Analyses of the data available are limited to generalizations about the presence of trace elements and to generalizations about the major ions. There are no trace elements that are in concentrations sufficient to cause any concern or cause rejection of the water supply.

The surface waters are generally of the sodium bicarbonate-magnesium sulfate type with total dissolved solids increasing downstream. The tributaries have a higher dissolved solids content than the upstream station 09306007 and would appear to contribute to the overall increase in dissolved solids at the downstream station 09306061. The water is used for agricultural purposes.

While chemical assessments are unlikely to change, continued monitoring will provide data on streamflow which will be invaluable to the extension of the baseline data.

3.2 Ground Water

3.2.1 Aquifer Tests

3.2.1.1 Rationale for Measurement

The total amount of ground water present under Tract C-b is known to be large, but estimates of the quantity existing in the interval down to the mining zone have varied widely. Estimates of the rate of inflow to an oil shale mine have varied even more widely. If excessive inflows are encountered, there is an adverse effect on mining economics as well as the possibility of severe environmental problems in disposing of the excess water.

The stratified structure of the sedimentary rocks below C-b results in a large variation of porosity, and horizontal and vertical permeability. Thus the total water in storage, the total water available from storage, and the rate of yield to a well or mine opening are all highly non-uniform, both areally and from one layer to the next. The development of a water management plan and the prediction of environmental impacts due to changes in the ground water regime require a knowledge of aquifer properties.

3.2.1.2 Objective

Primary objectives of this program included the determination of storage coefficients and hydraulic transmissivities for the aquifers near the Mahogany zone. Variations in both horizontal and vertical permeabilities with depth were to be determined.

Hydraulic characteristics of the alluvial aquifers were to be tested also.

3.2.1.3 Experimental Design

Short-duration pump tests were conducted in each of the alluvial wells.

During the drilling of the deep wells, a variety of jet tests, drill stem tests and multipacker tests were conducted to determine the variability of aquifer characteristics with depth.

A comprehensive aquifer pumping test was designed and conducted at a point near the center of the Tract, in the vicinity of the planned two vertical mine shafts. This test included pumping separately from above and below the Mahogany zone and observing the response in a number of observation wells completed in each aquifer. The locations of the pumped well, AT-1, and the observation wells were indicated in Figure 2-2.

Drilling of test well AT-1 commenced on June 15, 1974. It was drilled at a diameter of 12¼ inches to a depth of 1338 feet, just a short distance into the Mahogany zone. Steel casing was placed in the hole and an electric submersible pump was lowered to the bottom of the hole. A total of five close-in and four distant wells were equipped to monitor water levels during the test. A summary of the observation well locations and monitoring zones is given in Table 3-36. The orientation of the close-in observation wells is shown in Figure 3-33 and a schematic of the well completion intervals in Figure 3-34.

After pumping the upper aquifer, the pump was removed and well AT-1 was deepened to the bottom of the mining zone. Casing was installed and cemented in place. The well was then drilled another 270 feet down into the lower aquifer. A pump was then installed at the bottom (1430 feet) to test production from the lower aquifer.

A set of drill stem tests, referred to as the mini-pump tests, were conducted in the adjacent holes SG-1 and SG-1a. These tests were specifically designed to test the thesis that the thin bands of rich oil shale occurring above the Mahogany zone are significant barriers to vertical flow.

3.2.1.4 Methodology

Data from the aquifer tests were analyzed by a variety of methods. In the alluvial well pump tests, the test well also served as the observation well. Therefore the recovery method was used to evaluate the hydraulic conductivity. Drawdown data were also collected to evaluate the aquifer properties by the type-curve method of Glover.

Data from the drill-stem tests, upper and lower aquifer pump tests, and mini-pump tests were analyzed by type-curve methods, by analytical methods, and by history-matching with large-scale computer reservoir simulations.

3.2.1.5 Results and Discussion

3.2.1.5.1 Alluvial Aquifer Pump Tests

Alluvium is a potential source of water in the perennial stream

Table 3-36

AQUIFER TEST OBSERVATION WELL DATA

WELL NO.	DISTANCE (FEET) FROM AT-1	ZONES MONITORED
AT-1	-	Upper Aquifer
AT-1a	79 feet	Lower Aquifer Mining Zone
AT-1a1	85 feet	Upper Aquifer
AT-1b	102 feet	Upper Aquifer
AT-1c	102 feet	Upper Aquifer Mahogany Vugular Lower Aquifer
AT-1d	127 feet	Upper Aquifer Mahogany Vugular
SG-6	1289 feet	Upper Aquifer Mahogany Vugular Lower Aquifer
SG-10	2339 feet	Lower Aquifer Mahogany Vugular
SG-10a	2350 feet	Upper Aquifer
SG-11	3236 feet	Upper Aquifer Mahogany Vugular Lower Aquifer

Mahogany Vugular is the interval between the base of the Mining Zone and the B groove.

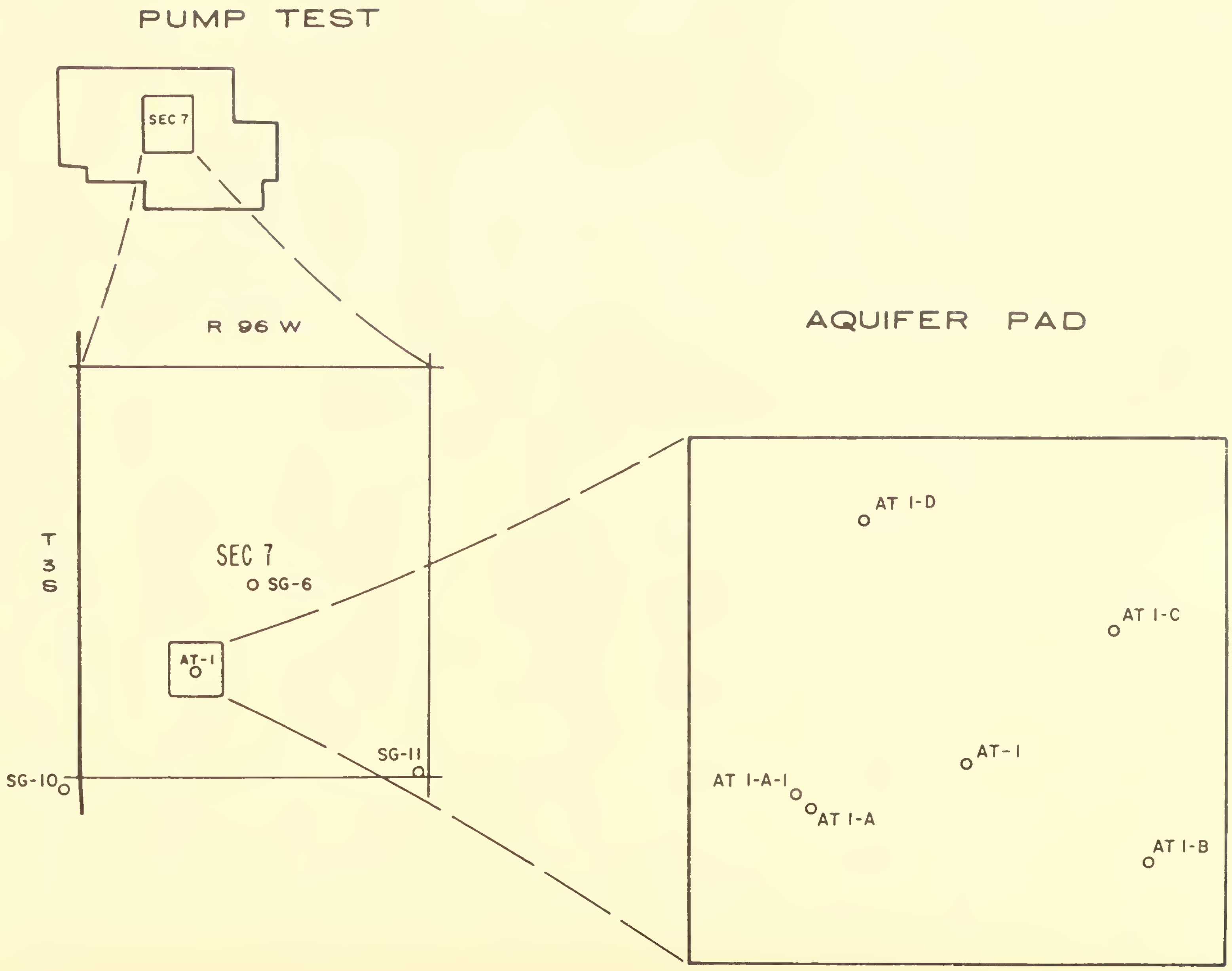
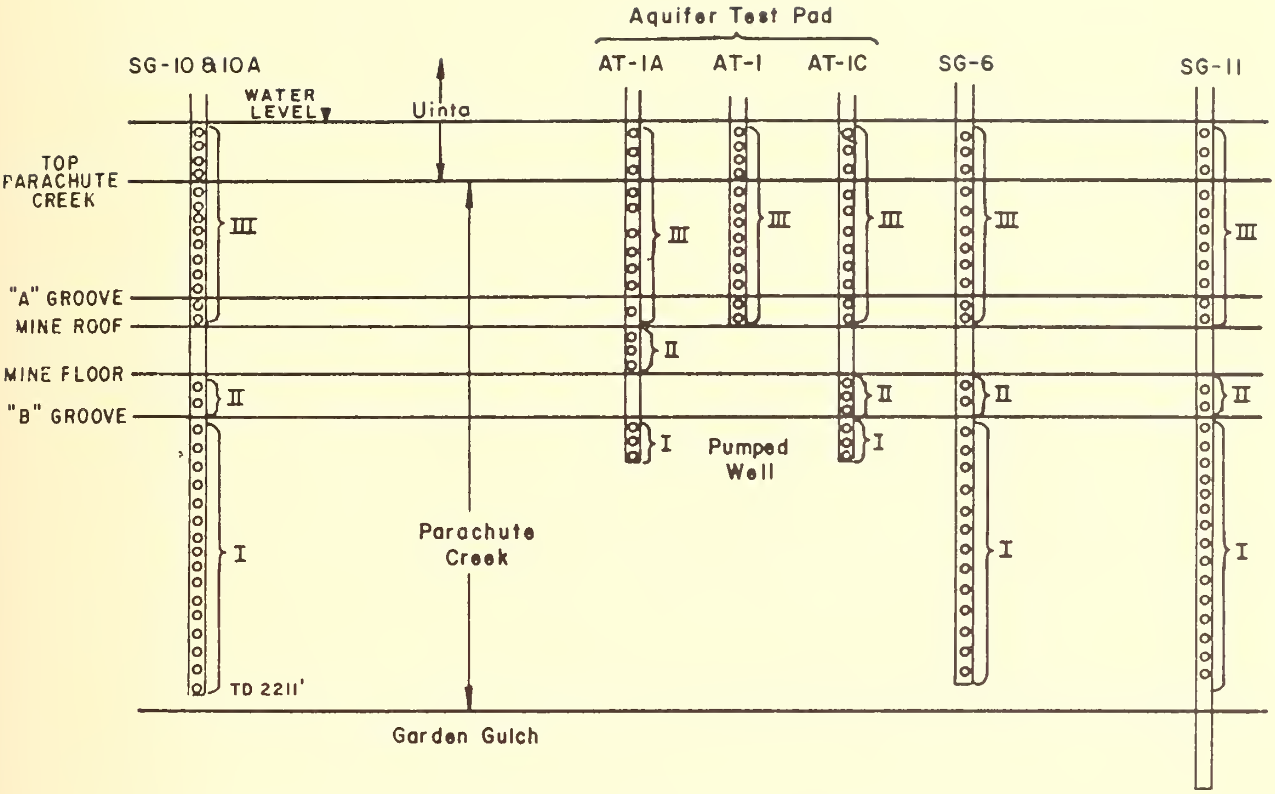


FIGURE 3-33

ORIENTATION OF AQUIFER TEST WELLS



SCHEMATIC CROSS-SECTION
UPPER AQUIFER PUMP TEST
C-b TRACT, COLORADO

SCALE: None

FIGURE 3-34

valleys of the Piceance Basin. The alluvium is as much as 140 feet thick, and is generally saturated below stream level. High well yields have been reported--as much as 1500 gpm--but the limited areal extent of the alluvium restricts high discharge rates to brief periods.

The alluvium is made up of sands, gravels, and clays eroded from sandstones, siltstones, and marlstones in the area. These deposits in Piceance Creek valley across the northern boundary of the C-b Tract are less than one-half mile wide. The depth to bedrock, established by the alluvial well drilling program, varies from 14 feet at A-13 in Upper Sorghum Gulch to 112 feet at A-3 in lower Scandard Gulch. The thickness of the alluvium in Piceance Creek valley varies from 51 feet in A-7 to 109 feet in A-1. Average thickness of the alluvium in Piceance Creek as determined by wells is approximately 77 feet.

In October 1975, aquifer tests were conducted on the eleven alluvial wells which yield water. In these tests the pumped well also served as the observation well. The Theis recovery method, using a modified equation for an unconfined aquifer, was used to evaluate the aquifer parameters. Drawdown data were also collected and analyzed by the type curve method of Glover (1974) to calculate maximum pumpage and the time required to reach maximum drawdown for the given discharge. Results are given in Table 3-37. Since the calculations are valid only for infinite aquifers and under other assumptions used in the development of the flow equations, the values listed must be considered as approximations only.

Being deposited in a narrow valley such as Piceance Creek, the stream alluvium is intermixed with alluvial fan deposits at the mouths of the tributaries and with colluvial deposits toward the edges of the valley. These disruptions in the homogeneity of the deposits have an effect on the transmissivity of the alluvial aquifers. Weeks, et al. (1974) report ranges of transmissivity from 2700 to 20,000 ft^2/day in the alluvium of Piceance Creek. The total range in transmissivity calculated from the C-b tests was from a low of 121 ft^2/day at A-9 in Stewart Gulch to a high of 10,000 ft^2/day at A-10 in the Middle Fork of Stewart Gulch. These figures, while not exactly comparable to those reported by Weeks, are generally within the lower range of his values.

Earlier pump tests in A-1 and A-2 were analyzed using the Jacob formula from a semi-log plot. Transmissivities were 1348 ft^2/day for A-1 and 359 ft^2/day for A-2.

An analysis of the data presented in Table 3-37 with respect to the location of the well shows no correlation between the data and the specific stream system. Other factors not discernible from the surface are involved. Such factors include the stratigraphy of the alluvium and the occurrence of clay beds as well as the geologic boundaries of the aquifer.

Table 3-37

AQUIFER PARAMETERS FROM ALLUVIAL PUMP TEST

WELL NO.	Aquifer (Saturated) Thickness (Ft.)	Hydraulic Conductivity (Ft./day)	Transmissivity		Intrinsic Permeability (Darcy)	Specific Yield	Maximum Pumpage (gpm)	Time Required to Reach Maximum Drawdown at Maximum Pumpage (Days)
			Gals./day/ft.	Ft.^{2}/day				
A-1	65.04	21.50	10,481	1,400	8.95	0.157	145	3,758
A-2	72.70	3.44	1,872	250	1.41	0.114	30	6,015
A-3	37.36	85.40	23,868	3,191	35.00	0.140	168	17,116
A-5	67.53	79.43	40,126	5,364	32.50	0.190	583	1,090
A-6	26.70	30.10	6,011	804	12.50	0.095	27	6.6×10^5
A-7	18.00	70.50	6,064	811	28.80	0.118	23	2,492
A-8	47.10	23.35	8,234	1,100	9.60	0.123	78	12,706
A-9	9.94	12.17	906	121	4.98	Not found	--	--
A-10	23.80	421.40	75,019	10,029	172.70	0.134	280	2.6×10^5
A-11	12.74	29.76	2,838	379	12.2	Not found	--	--
A-12	28.09	260.00	54,663	7,308	106.6	0.153	258	8.6×10^4

3.2.1.5.2 Drilling Water Production

As part of the general well histories, a record was maintained of the water discharge during drilling. A representative portion of these data is presented on Figure 3-35. In general three major water-producing zones are present beneath the Tract: (1) the interval immediately below the Four Senators; (2) A Groove; and (3) B Groove. Zones (1) and (2) are in the upper aquifer and Zone (3) is in the lower aquifer. In addition a minor water-producing zone of local extent occurs at the Uinta-Parachute Creek contact. Production for the entire interval was always less than 800 gallons per minute (GPM), the maximum rate that the water could be discharged during drilling.

Discharge generally increases as the well is deepened, but because water could flow out into unsaturated zones in the open hole, some wells occasionally show a decrease in discharge with increasing depth. This could also be due to local dewatering of limited aquifers. No lateral or areal patterns in water production rates could be seen.

Jetting tests were also conducted as part of the drilling program on the Tract. During actual drilling operations, both discharge (water production) rates and electrical conductivities of the produced water were routinely recorded at approximately 30-foot intervals as part of the general well history. In addition drilling operations were periodically shut down so that jetting tests could be conducted. In a typical deep well, jetting tests were performed at the following stratigraphic horizons: (1) base of the Uinta formation; (2) top of the Mahogany zone; (3) base of the Mahogany zone; (4) top of the R-4 zone; and (5) total depth.

During each jetting test, air was blown down the drill pipe to the bottom of the hole to force the water to flow up and out of the hole. Discharge rates and continuous electrical conductivity of the produced water were recorded. After jetting was halted, measurements were made of the rate at which the water returned to the static level. Using the discharge data and water level recovery rates, the transmissivities of the various horizons were calculated, as summarized in Table 3-38.

Again, because of open-hole conditions, these data must be considered only qualitative. Calculated transmissivities were highly variable, ranging from 1.34 to 1350 ft^2/day for the several wells drilled on Tract.

3.2.1.5.3 Drillstem Tests

Drillstem tests were conducted in three wells drilled on the Tract. The most comprehensive testing program was conducted in SG-17 where nearly 40 drillstem tests were run. Two drillstem tests were also run in each of the core holes SG-20 and SG-21.

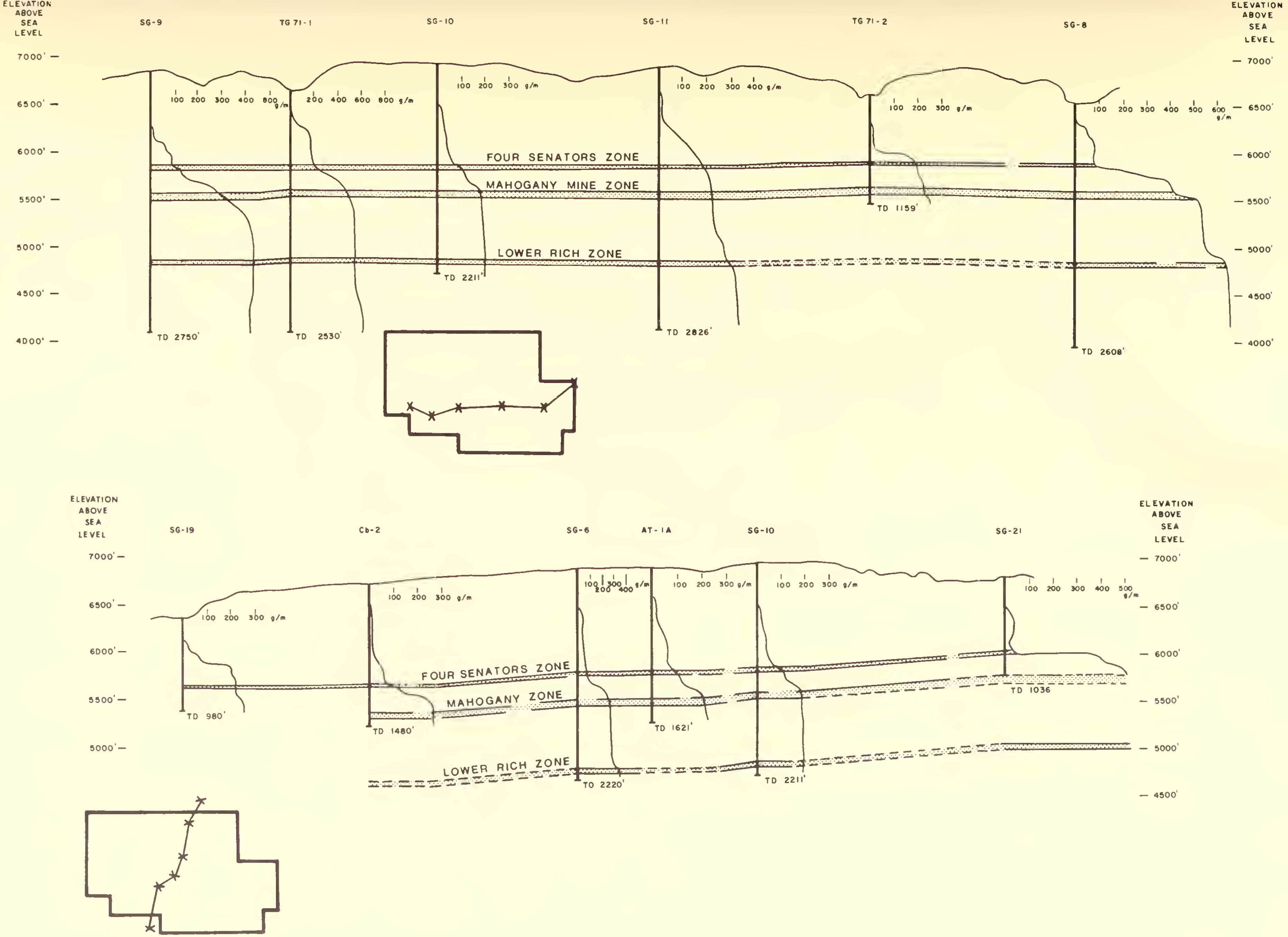


FIGURE 3-35 NORTH-SOUTH AND EAST-WEST STRATIGRAPHIC SECTIONS SHOWING WATER PRODUCTION CURVES

Table 3-38 WELL DATA FROM JET TESTING

Well No.	Depth of Test	Transmissivity ft^2/day	Conductivity Micromhos	Production gal/min.
Cb-1	1280	134	1820	178
	1480	167	2000	-
	2100	195	3000	386
Cb-2	1280	668	2600	328
	1480	1203	2400	326
Cb-3	1240	869	2460	250
	1450	989	2400	300
	2122	1176	3040	350
Cb-4	1250	58.8	870	100
	1468	321	1010	230
SG-1	600	762	1000	610
	700	709	950	565
	1040	634	1000	467
	1105	820	1000	673
	2220	1158	2000	794
	2525	989	1900	840
SG-6	845	21.4	850	18
	1320	251	1250	189
	1440	330	1250	211
	1520	368	1300	211
	2220	439	1400	224
SG-8	600	334	1600	72
	970	540	1620	251
	1000	805	1600	251
	2115	1114	2400	494
	2608	1350	2600	458
SG-9	990	30.7	850	54
	1285	136	1200	282
	1360	179	1200	260
	2540	386	1100	274
	2750	310	1050	202
SG-10	960	23.5	-	21
	1330	398	850	148
	1430	402	900	167
	2211	1013	2100	152
SG-11	810	134	1180	112
	860	118	950	108
	1330	685	1005	176
	1390	566	1050	-
	1490	316	1200	108
	2465	752	2050	234
	2826	802	2250	148
SG-17	830	28.9	800	27
	1250	256	1400	103
	1330	284	-	153
	1622	271	1200	184
	2460	118	4400	162
SG-21	960	1.34	1100	11
	1036	660	600	292
TG-71-1	700	294	1140	200
	1040	802	9250	860
	2080	-	3300	-
	2150	-	1480	-
	2260	-	2800	-
	2300	-	3980	-
	2400	-	2500	-
	2530	450	2740	660
TG-71-2	630	-	760	-
	720	-	1100	-
	1000	628	-	-
	1162	615	-	-

In conducting each drillstem test, a packer was lowered on drill pipe to a predetermined depth. The packer was set (expanded) isolating the lower part at the hole. Water was jetted out of the drill pipe from the interval below the packer for a predetermined length of time. During jetting, discharge was measured and water samples collected. After the jetting was terminated, the rise or recover in water level in the packed-off zone was recorded. Using discharge and recovery data, calculations were made of horizontal permeability.

The drillstem test has several important advantages over routine jetting tests:

(1) It allows a direct calculation of horizontal permeability for a particular small interval in the hole.

(2) It allows the collection of a water-quality sample from a small discrete subsurface interval.

(3) It can be used to provide a permeability and water-quality profile of how conditions change with depth.

In addition to the standard, single-packer drillstem tests, more sophisticated multi-packer tests were also conducted during the drilling of SG-17. A three-packer tool was assembled in which water could be selectively injected into very small packed-off intervals. Twelve intervals were tested by this method. In all the tests water was injected into the primary packed-off interval at rates of 5, 10, 20 and 20+ gallons per minute. The change in pressures in the various zones was recorded. After completing the injections, the tool was loosened, raised to a higher interval and another test was run.

The principal objective of the multi-packer testing was to determine vertical permeability. The configuration of the tool and packer assembly permits the collection of pressure data which theoretically can be reduced to yield vertical permeability values.

Horizontal permeability values determined by drillstem tests and multi-packer tests are summarized in Table 3-39. The evaluation was done by computer, using oil-field analytical techniques and the data were reported in millidarcies (md). The greatest horizontal permeability is 300 md, the smallest is 1.6 md. The test results indicate that vertical permeabilities were too low to be accurately determined by this testing procedure.

3.2.1.5.4 Aquifer Pumping Test

The main aquifer test was designed to determine the hydraulic characteristics of the upper and lower aquifers beneath the Tract as defined by the USGS in its regional model of the basin. The main aquifer test area was located near the center of the Tract (Figure 2-2). Two separate tests were conducted. The first test consisted of a central pumping well surrounded by eight monitoring wells. The pumping well

Table 3-39 SG-17 DRILLSTEM AND MULTI-PACKER TESTS

DRILLSTEM TESTS

DST No.	Interval, feet	Permeability, md.
1	386-436	N.D.
2	788-808	N.D.
3	822-869	11.0
4	866-919	12.7
5	919-970	34.0
6	967-1017	10.7
7	1017-1067	19.9
8	1066-1116	20.0
9	1116-1166	8.0
10	1164-1212	185.0
11	1200-1224	21.2
12	1215-1224	20.8
13	1224-1251	300.
14	1251-1271	8.0
15	1280-1309	13.0
16	1309-1336	N.D.
17	1327-1373	52.
18	1373-1419	15.
19	1423-1470	N.D.
20	1423-1470	23.9
21	1473-1522	3.0
22	1428-1522	4.7
23	1512-1572	4.0
24	1561-1572	23.0
24 (J)	1561-1622	N.D.
25	1618-1640	4.0
25 (J)	1618-1670	1.6
26	1668-1679	30.0
26 (J)	1668-1720	7.3
27	1711-1770	6.0
28	1768-1779	42.0
28 (J)	1768-1820	9.8
29	1818-1870	2.0
30	1869-1880	275.
30 (J)	1869-1910	30.
31	1918-1970	4.0
32	1966-2020	169.
33	2018-2070	N.D.
34	2120-2170	30.
35	2220-2270	N.D.
36A	2320-2370	N.D.
36B	2315-2370	N.D.
37	2395-2460	35.

(J) - Jetting Test

MULTI-PACKER TESTS

MPT No.	Interval, feet	Permeability md.
1	1089-1114	75
2	1123-1148	N.D.
3	1147-1172	92
4	1184-1209	N.D.
5	1338-1363	N.D.
6	1422-1447	N.D.

N.D. - No data obtained due to equipment malfunction, analytical problems, no water injection, packer leakage, etc.

was completed in the upper aquifer. Monitoring wells were completed with multiple strings of tubing and packers which isolated the upper and lower aquifers in the observation wells. The producing well was pumped for 30 days, allowed to recover for 5 days, pumped for an additional five days and finally allowed to recover for 30 days. Responses of the upper and lower aquifers in the observation wells were recorded. Discharge rates, water level measurements and water production rates of the pumping well were continuously recorded. Water samples were collected on a regular basis.

The second main aquifer test was identical in concept with the first, except that the pumping well was deepened and recompleted so that only the lower aquifer would be pumped. In this test the producing well was pumped for 18 days, allowed to recover for eight days, pumped for an additional eight days and finally allowed to recover for 20 days. Based on these data, computations have been made of transmissivity, storage coefficient and water production of the upper and lower aquifers. Vertical hydraulic conductivity of the Mahogany zone was also determined.

These aquifer tests were designed to obtain transmissivities and storage coefficients of the upper and lower aquifers and the leakance across the Mahogany zone. Data were analyzed using the equations for leaky artesian reservoirs from R.E. Glover's "Transient Ground Water Hydraulics" (1974). Results of the computations are summarized on Table 3-40. Data from the upper main aquifer test have good consistency. Close-in wells exhibit good curve-fits to the data. The more distant wells approximate the type-curve analysis only reasonably well. Transmissivity of the upper aquifer ranges from 233 ft^2/day to 128 ft^2/day and arithmetically averages 168 ft^2/day. The storage coefficient in the upper aquifer averages 5.04×10^{-4} and varies from 1.68×10^{-3} to 6.92×10^{-5}. Vertical leakance into the pumped aquifer ranged from 6.0×10^{-6} day^{-1} to 4.25×10^{-7} day^{-1}. The average discharge of the pumped well over the drawdown period was 373 GPM. During the upper test no drawdown was noted in the lower aquifer, which establishes that no measurable vertical leakage occurred through the Mahogany zone during this test.

The analyses of the lower main aquifer drawdown test also show a good fit of the observation well data to the type curves. The transmissivity ranges from 14.7 ft^2/day to 91.9 ft^2/day. The arithmetic average transmissivity is 40.4 ft^2/day. The storage coefficient is generally only half as large as in the upper aquifer with an average storage coefficient of 1.73×10^{-4}. Storage coefficients range from 5.3×10^{-4} to 1.21×10^{-5}. Computed leakance values are of the same order of magnitude as in the upper aquifer, ranging from 3.93×10^{-7} to 1.96×10^{-5} day^{-1}. The average yield of the well during this test was 120 GPM. Linear data plots show no measurable water movement vertically downward through the Mahogany zone during the pumping of the lower aquifer.

During both main aquifer tests significant anisotropic flow was

Table 3-40 RESULTS OF AQUIFER PUMP TESTS

UPPER AQUIFER

Well Number (String #)	Transmissivity ft^2/day	Storage Coefficient	Leakance day-1
SG-10	233	4.21×10^{-4}	4.26×10^{-7}
AT-1A(#3)	159	4.23×10^{-4}	6.10×10^{-6}
SG-6	212	1.68×10^{-3}	1.27×10^{-6}
AT-1D(#3)	130	2.97×10^{-4}	8.05×10^{-7}
AT-1B	162	3.71×10^{-4}	1.56×10^{-6}
AT-1C	128	2.73×10^{-4}	1.23×10^{-6}
SG-11	155	6.92×10^{-5}	5.90×10^{-7}

LOWER AQUIFER

Well Number (String #)	Transmissivity ft^2/day	Storage Coefficient	Leakance day-1
AT-1C(#2)	20.4	1.22×10^{-4}	1.96×10^{-5}
AT-1C(#1)	40.9	1.21×10^{-5}	3.93×10^{-7}
AT-1D(#1)	35.4	2.67×10^{-5}	8.77×10^{-7}
SC-6(#1)	91.9	5.30×10^{-4}	
AT-1D(#1)	43.8	4.19×10^{-4}	
SG-6(#2)	35.7	6.48×10^{-5}	3.44×10^{-6}
SG-10(#10)	14.7	3.92×10^{-5}	6.88×10^{-6}

noted. Well SG-11 was noted to drop much more rapidly than the two closer wells, SG-6 and SG-10. Computations analyzing the drawdown relationship, using R. E. Glover's equations for anisotropic analysis, derived a greatest-permeability direction for the upper aquifer as being in the east-northeast direction from the pumped well with a ratio of 9:1. Because of limited data in the lower aquifer, the analysis can only state in general that the direction of greatest permeability lies in a more north-south direction.

3.2.1.5.5 Mini-Pump Tests

A series of short-term pump tests (called the mini-pump tests) were conducted on two wells (SG-1 and SG-1A), located about 100 feet apart in the northwest corner of the Tract (Figure 2-2). The principal purpose of this test series was to determine the extent to which thin zones of rich oil shale act as aquitards and restrict vertical flow.

The mini-pump tests consisted of a pumping well (SG-1A) and an observation well (SG-1). By means of multiple-packer arrangements, the same aquifer unit was isolated in both the pumping and observation well. Recording devices were placed in the observation well to measure vertical flow through the aquitards into the isolated aquifer. Four intervals were tested using this procedure. The pumping periods lasted from 12 to 24 hours followed by recovery periods of two to six hours. The amount of water discharged by the pumping well was measured during the testing of each unit. From the information collected, computations were made of the vertical hydraulic conductivity of several aquitards. Transmissivities and storage coefficients of the four individual aquifer units were also determined. Water-quality samples were taken on a regular basis during testing and water electrical conductivity was recorded hourly.

The mini-pump tests were mainly designed to determine the extent to which thin, rich, oil shale zones restrict vertical water flow. Using approximations of the aquitard thicknesses derived from geophysical logs, the computed leakance varies from 3.20×10^{-7} to 7.58×10^{-4} day^{-1}. The vertical hydraulic conductivities, using estimated aquitard thicknesses, range from 3.06×10^{-6} to 4.55×10^{-3} ft/day. From these analyses and those of the main aquifer tests, it can be seen that leakance and actual vertical permeabilities are very small. The transmissivities obtained from the mini-pump tests are also small, ranging from 1.71 ft^2/day to 18.4 ft^2/day. The storage coefficient is in the same order of magnitude as the main aquifer tests previously discussed, ranging from 2.08×10^{-4} to 1.20×10^{-3}. Results of the individual aquifer tests are summarized in Table 3-41.

3.2.1.5.6 Analytical Evaluation of Hydraulic Conductivity

The drillstem tests and mini-pump tests have established the presence

Table 3-41 RESULTS OF MINI PUMP TESTS

Test Number	Transmissivity ft^2/day	Storage Coefficient	Leakance day-1	Vertical Hydraulic Conductivity ft/day
Test #4	1.71	$2.08 X 10^{-4}$	$3.20 X 10^{-7}$	$3.06 X 10^{-6}$
Test #6	5.27	$9.13 X 10^{-4}$	$7.58 X 10^{-4}$	$4.55 X 10^{-3}$
Test #8	18.4	$4.34 X 10^{-4}$	$1.84 X 10^{-5}$	$3.06 X 10^{-6}$
Test #10	11.6	$1.20 X 10^{-3}$	$4.63 X 10^{-5}$	$2.78 X 10^{-4}$

of two major zones of low permeability. The Four Senators zone and the Mahogany zone both restrict vertical flow, as confirmed by distinct variations in water chemistry.

In addition to the major aquitards, thin, rich, oil shale layers within the main oil shale zones further inhibit vertical movement of water. The main aquifer and mini-pump test results, as calculated by the type-curve method, indicate that local vertical leakance within the upper and lower aquifers is one to two orders of magnitude smaller than USGS regional values. The type-curve method, however, may lead to significant errors owing to assumptions employed in the derivation of the curves. The aquitards themselves can play an important role in the hydrology of multiple aquifer systems. Analyses are commonly simplified by assuming that vertical components of flow within the aquifers and horizontal components of flow with the aquitards are negligible. These assumptions are generally valid, since the contrast in hydraulic conductivity between the aquifers and aquitards is usually large.

A complete analytic solution for this problem has been developed by Newman and Witherspoon (1969). Effects of storage in the aquitard and drawdown in the unpumped aquifer are both considered. A computer program was developed to calculate a numerical solution of their analytical expression. During the upper aquifer pump test, when the entire saturated section above the Mahogany zone was pumped at well AT-1, no measurable drawdown was noted in the lower aquifer at well AT-1c, 102 feet away (See Figure 3-36). Pumping was maintained for 550 hours. A computer solution was therefore calculated for 550 hours of pumping and several different values of vertical hydraulic conductivity.

Assuming that the pressure bomb used to record drawdown in the pump test was sensitive to pressure fluctuations of about 0.5 ft., the calculated results indicate that the true value of vertical conductivity is less than 5×10^{-7} ft/day (See Figure 3-37). That is, at 550 hours the drawdown should be about two feet for a vertical hydraulic conductivity of 5×10^{-7}. Since no drawdown of this magnitude was observed, it can be concluded that the conductivity in the vertical direction is substantially lower than that calculated by the type-curve method. Vertical flow will be negligible in comparison to horizontal flow.

A comparison of C-b data with the USGS report shows that storage coefficients and horizontal hydraulic conductivity are both smaller than the values used by USGS to represent the Basin as a whole.

3.2.1.5.7 Barometric Efficiency

The storage coefficient of an aquifer is defined as the volume of water an aquifer releases from or takes into storage per unit

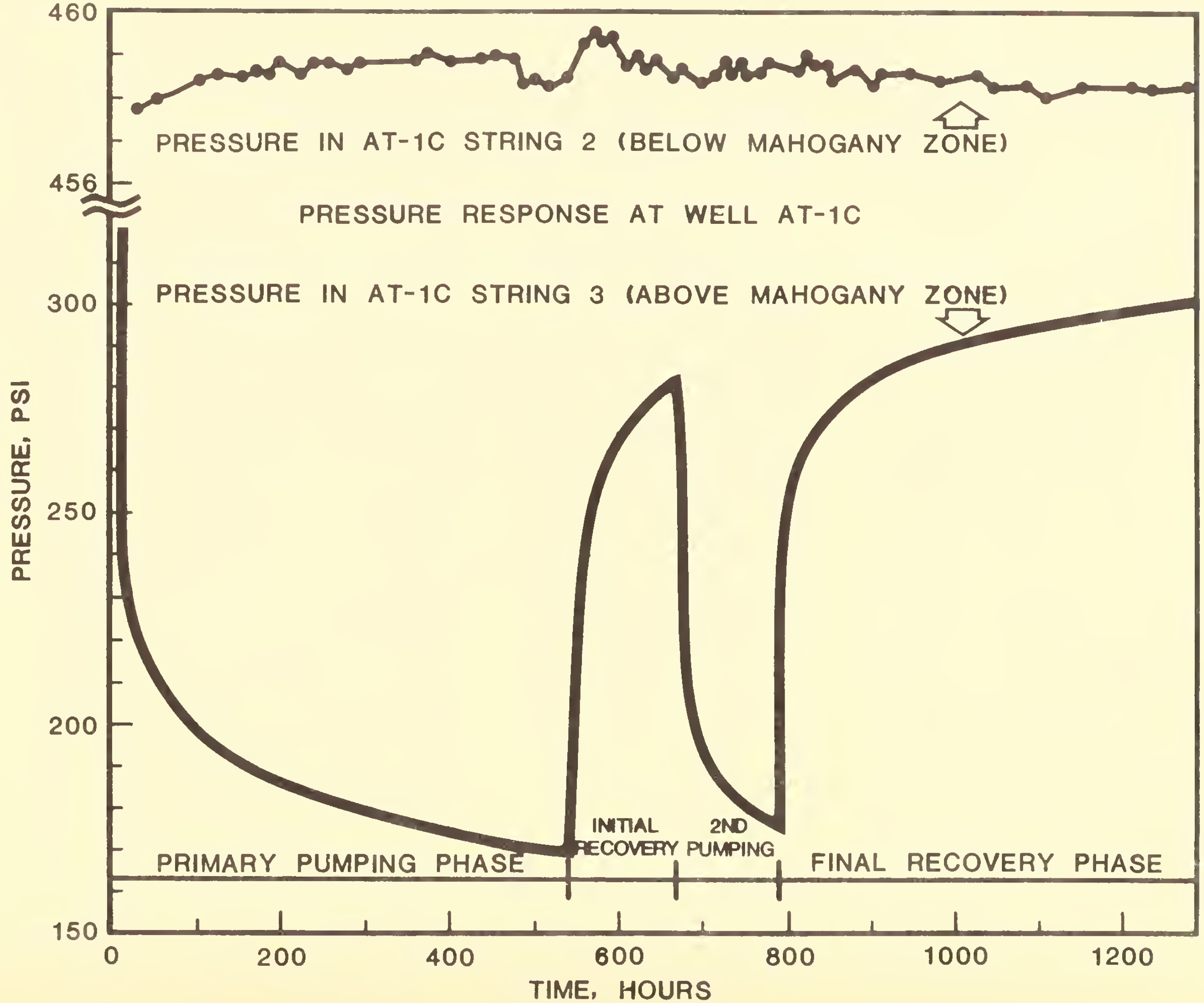
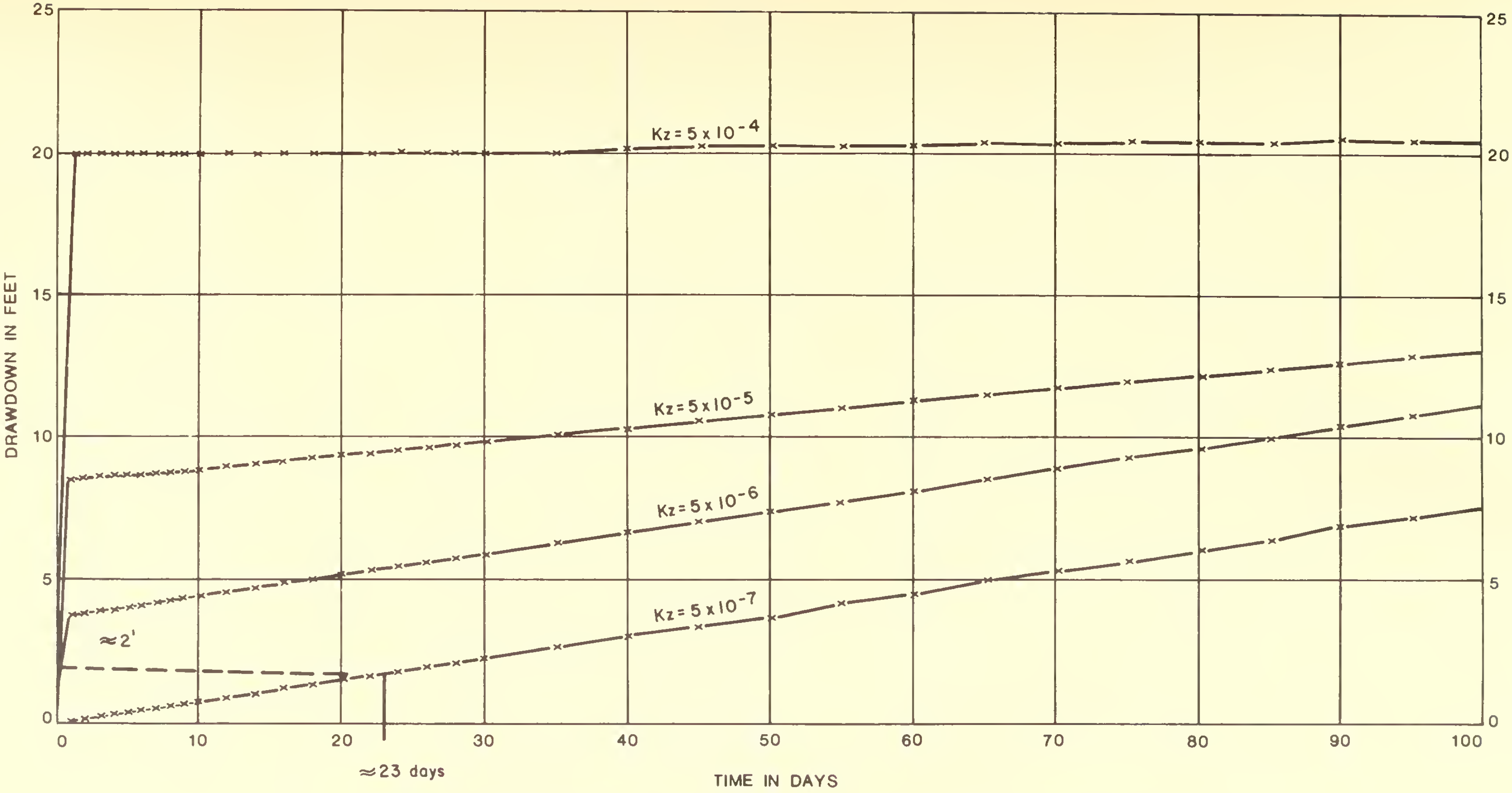


FIGURE 3-36 AQUIFER TEST RESPONSE AT WELL AT-1C



K_z = VERTICAL HYDRAULIC CONDUCTIVITY OF MAHOGANY ZONE IN FEET/DAY. PUMPING RATE IN THE UPPER AQUIFER = 373 GPM. DRAWDOWN WAS COMPUTED AT A RADIAL DISTANCE OF 102 FEET.

DRAWDOWN IN LOWER AQUIFER DUE TO PUMPING OF UPPER AQUIFER FOR DIFFERENT VALUES OF CONDUCTIVITY OF MAHOGANY ZONE

FIGURE 3-37

surface area of the aquifer per unit change in head. Changes in the quantity of water in storage result from: (1) changes in the porosity of the medium, (2) deformation of the boundaries of the aquifer, (3) compression or expansion of the water itself.

Results from the aquifer pump tests, given earlier, showed the storage coefficient of the lower aquifer to be on the order of 1×10^{-4}. This is about average for confined aquifers, which generally range from 10^{-3} to 10^{-5} and are about 10^{-6} per foot of thickness. In an open well completed in a confined aquifer, an increase in barometric pressure will have the same effect as an increase in water level, i.e., compression of the water and the aquifer matrix, causing an increase in storage. An approximate relationship can be derived between the barometric efficiency of a well and certain properties of the aquifer and of water.

Barometric efficiency is defined as the ratio of the net change in water level observed in the well to the corresponding change in barometric pressure, measured as height of water column. From Figure 3-38, the barometric efficiency of the lower aquifer at well AT-1 is about 48 percent. The storage coefficient is related by: $S = \frac{\Theta\, d\, b}{E_W\, E_b}$

Where

S = storage coefficient (dimensionless)
Θ = aquifer porosity (dimensionless)
d = specific weight of water (0.434 lb in^{-2} ft^{-2})
b = aquifer thickness (ft)
E_W = bulk modulus of elasticity of water (3×10^5 lb in^{-2})
E_B = barometric efficiency (as a fraction)

Assuming that the lower aquifer extends from the Mahogany zone to the lower rich zone (735 ft), the above equation can be rearranged to calculate the aquifer porosity:

$$\Theta = \frac{(0.48)(1 \times 10^{-4})(3 \times 10^{5})}{(0.434)\ (735)}$$

$$= 0.05$$

3.2.2 Water Level Records

3.2.2.1 Rationale for Measurement

Ground water discharge provides the major base flow for surface streams in the Piceance Creek basin. Changes in ground water levels can be expected to produce corresponding changes in discharge rates. Because water is a scarce commodity in the C-b area, any effects due to development will be closely watched, both from the environmental

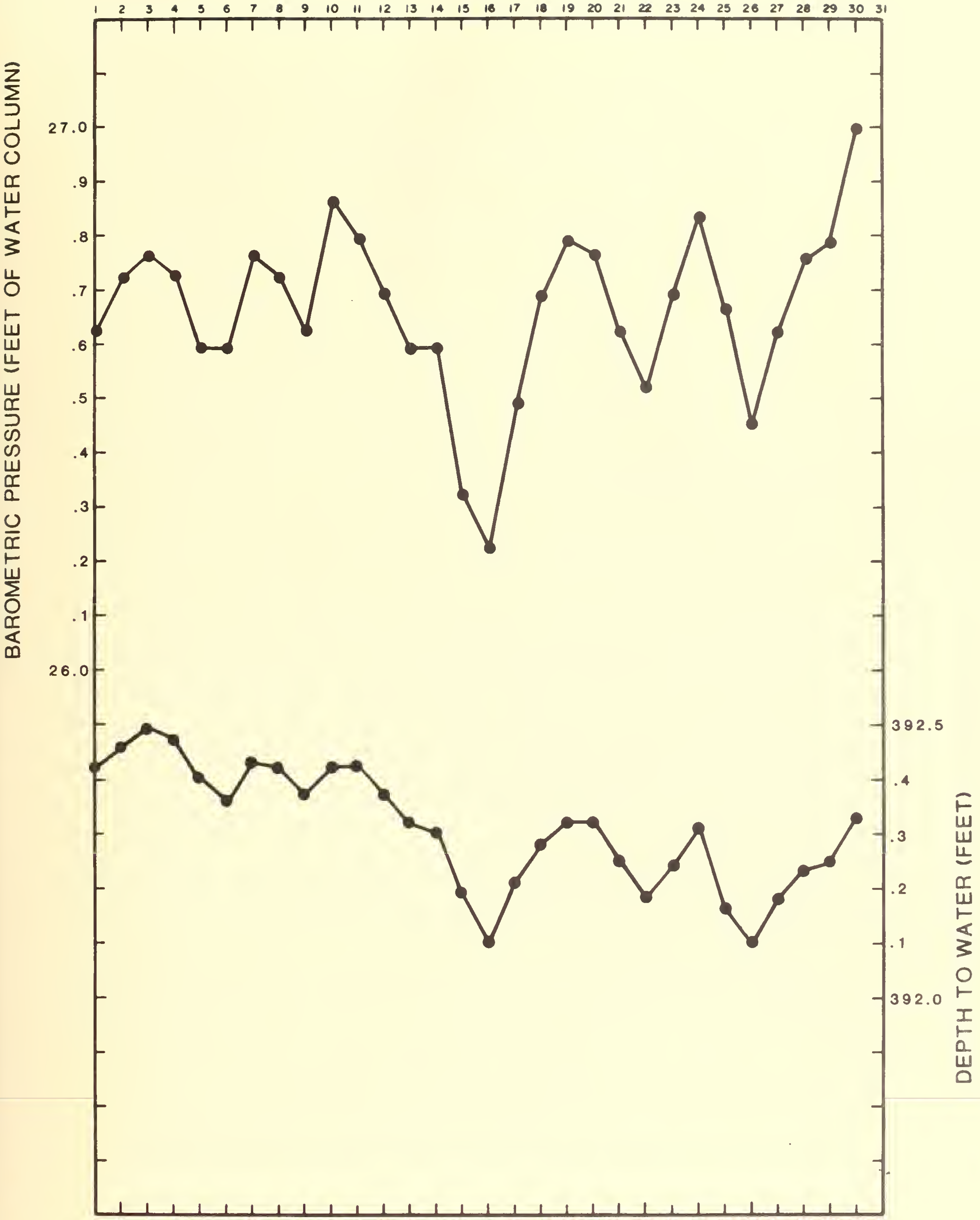


FIGURE 3-38 WELL AT-1

APRIL, 1976

standpoint and from the standpoint of downstream water rights.

Flow rates in surface springs and streams, water levels in alluvial aquifers and water levels and regional flows in the deep aquifers may all be affected by mine dewatering activities.

A record of baseline water levels in all aquifers which may be connected to surface flows is necessary to gauge the future effects of mine development.

3.2.2.2 Objective of Program

The ultimate goal of collecting water level data is to provide baseline data and the input for a mathematical model capable of accurately simulating the total hydrological regime surrounding Tract C-b. This model can then be used to calculate long-term effects and to simulate the results of such things as mine water reinjection and ultimate mine abandonment.

3.2.2.3 Experimental Design

Water level measurements are subject to only two basic variables in experimental design--well locations and frequency of measurement. Deep well monitoring wells were generally derived as a secondary development from the corehole drilling program. Corehole locations were chosen on the basis of need for geological information on oil shale assays and rock properties. Only those deep wells associated with the aquifer pump test were drilled specifically for hydrological information. In spite of the subordinate nature of hydrological specifications for the locations of deep wells on the Tract, the large number of wells drilled presents sufficient locations for thorough coverage of ground water levels. Well locations were shown in Figure 2-2.

Alluvial well locations were chosen so as to monitor water levels in the alluvial fill of each separate valley drainage. Alluvial well locations also were shown in Figure 2-2.

Normal measurement frequency was set at once per month. This is often enough to clearly delineate any seasonal fluctuations correlated with precipitation patterns. In addition to periodic (monthly) measurements, an attempt was made to provide continuous monitoring of selected wells. This would make it possible to observe any rapid small-scale fluctuations, such as that due to barometric pressure variations, but the chief objective of installing continuous monitors was simply to conserve manpower and increase the reliability of measurements. It would be highly improbable, under baseline conditions, for any significant ground water change to occur too rapidly for detection at monthly intervals.

3.2.2.4 Methodology

Monthly level measurements are taken with manually operated well sounders. "Powers," "M-Scope" and "Soil-Test" models have been used. These instruments are a simple reel filled with two-strand conductive wire with a handle for winding and a meter to indicate electrical contact when water fills the gap between the two exposed ends of the wire. Depth is determined from metal markers attached to the cable at 10-foot intervals. When the water level is located by watching the meter response, the exact depth is determined by measuring the distance from the measuring point (MP, the top of the well casing or other reference point) to the nearest marker with a steel tape. Possibilities for error include the occasional slippage of a marker along the cable, stretching of the cable with repeated use, elastic stretch due to the considerable weight of the suspended cable when measuring deep wells, difficulty in locating the water interface due to oil or kerogen on the surface, and human error in reading either the cable marker or the steel tape.

Continuous water level measurements were attempted initially on 15 well strings. The instrumentation consisted of a transistorized level-seeking motor and reel assembly, with the wire from the reel looping around a drive pulley on a "Stevens" digital paper tape recorder. The recorder was battery-powered, with a clock mechanism causing the water depth to be punched on tape at hourly intervals. These units could achieve an extremely fine discrimination of changes in water level, down to 0.01 feet. Although all the units worked well when installed, many became inoperative within a few weeks or months, and others were found to be giving incorrect readings. It is thought that most of the problems were due to the oily material or kerogen found in most of the deep wells. This material would coat the sensing probe and the inside surface of the well bore, causing a marked change in electrical resistance between the two. Being unable to distinguish the water interface, the motor would unwind the reel completely, usually resulting in a tangle of cable and/or a broken cable and inoperative unit. In some cases the probe would apparently locate a point where deposits on the tubing wall thinned, making electrical contact possible, and stabilize at this point instead of the interface. Since this point could be very near the interface, no discrepancy could be detected by manual measurement until after the water level had risen appreciably. After much unsuccessful effort to obtain satisfactory operation, the continuous monitors were abandoned except for two wells with large-diameter casing, in which the instruments seemed to experience fewer problems.

3.2.2.5 Results and Discussion

3.2.2.5.1 Alluvial Wells

Reduced water level data, shown as elevations above sea level, are listed in Table 3-42. Complete charts for individual wells may

Table 3-42 WATER LEVELS IN ALLUVIAL WELLS

	A-1	A-2	A-3	A-4	A-5	A-6	A-7	A-8	A-9	A-10	A-11	A-12	A-13
Ground Level	6279	6281	6447		6343	6358	6382	6406	6538	6608	6502	6690	
M.P. Elevation	6282.2	6284.5	6448.6		6345.0	6360.0	6383.8	6409.0	6540.2	6610.6	6503.8	6691.8	
September 1974							6350.6		6492.0	6565.6	6448.7	6636.9	
October 1974	6236.5	6268.1	6374.1		6325.0	6325.1		6384.3					
December 1974	6235.9	6271.6	6376.5		6325.7	6327.9	6351.1	6385.5	6493.0	6567.1	6449.5	6639.0	
January 1975	6235.2	6271.8	6374.1		6325.6	6325.8	6350.8	6385.9	6492.3	6565.3	6449.6	6637.8	
March 1975	6233.3	6269.0	6372.0		6325.9	6323.5	6349.9	6382.4	6490.3	6564.4	6448.3	6638.5	
June 1975	6238.0	6271.7	6377.3		6326.5	6332.5	6354.0	6386.0	6491.7	6569.3	6449.2	6638.5	
July 1975	6240.0	6271.4	6372.8		6325.9	6330.0	6356.0	6385.6	6491.6	6568.4	6449.1	6637.7	
August 1975	6239.9	6270.3	6374.1		6325.7	6332.5	6354.0	6385.3	6491.4	6564.7	6448.9	6637.0	
September 1975	6237.9	6271.9	6373.5		6325.8	6327.1	6350.3	6383.6	6491.5	6567.4	6448.9	6636.7	
October 1975	6236.7	6273.5	6372.3		6325.8	6325.1	6351.4	6384.5	6492.1	6567.1	6448.9	6637.5	
November 1975	6235.2	6273.8	6371.5		6325.9	6327.0	6348.3	6380.0	6492.0	6565.5	6448.8	6636.4	
December 1975	6235.5	6269.7	6370.9		6325.7	6325.3	6347.8	6384.1	6491.8	6566.0	6449.2	6637.0	
January 1976	6233.9	6269.6	6369.7		6325.5	6324.5	6347.3	6383.8	6491.6	6565.7	6449.4	6637.3	
February 1976	6233.8	6268.4	6369.1		6325.4	6324.1	6346.8	6384.6	6491.5	6565.0	6449.6	6637.6	
March 1976	6233.8	6268.5	6370.9		6325.4	6324.7	6347.7	6386.4	6491.8	6565.0	6450.2	6638.0	
April 1976	6233.8	6269.0	6369.1		6325.5	6324.6	6346.3	6385.8	6491.8	6565.0	6450.1	6638.9	
May 1976		6269.0	6368.4		6325.8	6330.8	6344.2	6383.8	6491.3	6565.4	6450.2	6639.4	
June 1976	6233.4	6269.0	6370.8		6326.2	6331.0	6354.2		6492.0	6562.2	6450.1	6639.5	
July 1976	6237.6	6268.5	6372.4		6325.4	6331.6	6356.9	6383.1	6490.6	6560.7	6450.7	6638.1	
August 1976	6238.2	6268.6	6372.4		6325.4	6332.4	6353.7	6383.9	6490.6	6559.8	6449.9	6638.6	
September 1976	6236.6	6271.0	6371.8		6325.5	6327.4	6351.7	6385.7	6490.2	6559.5	6449.0	6637.6	
October 1976	6233.8	6269.4	6370.6		6326.0	6326.4	6349.7	6382.3	6488.8	6560.2	6448.8	6637.0	
November 1976	6235.3	6270.3	6372.3		6326.1	6328.8	6349.6	6382.4	6491.3	6559.4	6448.6	6636.9	
Mean	6235.9	6270.2	6372.1		6325.7	6327.6	6350.6	6384.2	6491.4	6564.5	6449.4	6637.8	

be found in Figures A-17 through A-27 in the appendix. Although the data exhibit considerable scatter, a definite seasonal cycle can be discerned. Most wells show a peak water level in June or July and a minimum in February or March. The overall trend can best be seen by averaging the readings of all wells. This is done by first computing the mean water level for each well, then calculating each month's reading as a deviation from the mean, followed by a determination of the average of all well deviations for each month.

The results of the above calculations are plotted in Figure 3-39. The June-July peaks are probably the delayed result of maximum infiltration and recharge from the snowmelt runoff period which occurs approximately two months earlier. Soil moisture measurements have shown the peak level of soil moisture from snowmelt to occur in April.

The greater height of the 1975 peak as compared to the 1976 peak may not be significant. Snowpack measurements indicated a considerably larger water equivalent in the 1976 average snow depth than in 1975. The two peaks in well water level are superimposed on a generally declining water level from 1975 to 1976. This too is opposite to what would be expected as a result of the difference in snowpack for the two years.

Inspection of the individual water level charts (Appendix) shows some wells with much wider fluctuations than others. This observation can be quantified by calculating the average deviation (absolute value) from the mean for each well over the total time period. These numbers are listed in Table 3-43 along with the saturated thickness of alluvium at each well and the average difference between 1975 and 1976 levels.

There is no direct relationship between saturated thickness and the magnitude of fluctuations in the aquifer. It may be noted that the largest average deviations occurred at wells A-6, A-7, and A-10, which are located in Cottonwood Gulch, Sorghum Gulch, and Middle Stewart Gulch, respectively. The corresponding surface water gauging stations are 09306039, 09306036, and 09306015, respectively. These are all locations with only sporadic surface flows. Thus recharge to the aquifers from surface flow in the gulches is highly irregular and could be expected to result in wide variations of water level.

Wells A-6, A-8, A-11, and A-12 show a small increase between 1975 and 1976 average levels. All other wells show declines from 1975 to 1976. The contrast between alluvial water levels and depth of snowpack for the two years is unexpected and does not present a ready explanation.

3.2.2.5.2 Upper Aquifer Wells

Reduced water level data, as elevations above sea level, are listed in Table 3-44. Complete charts for individual wells may be

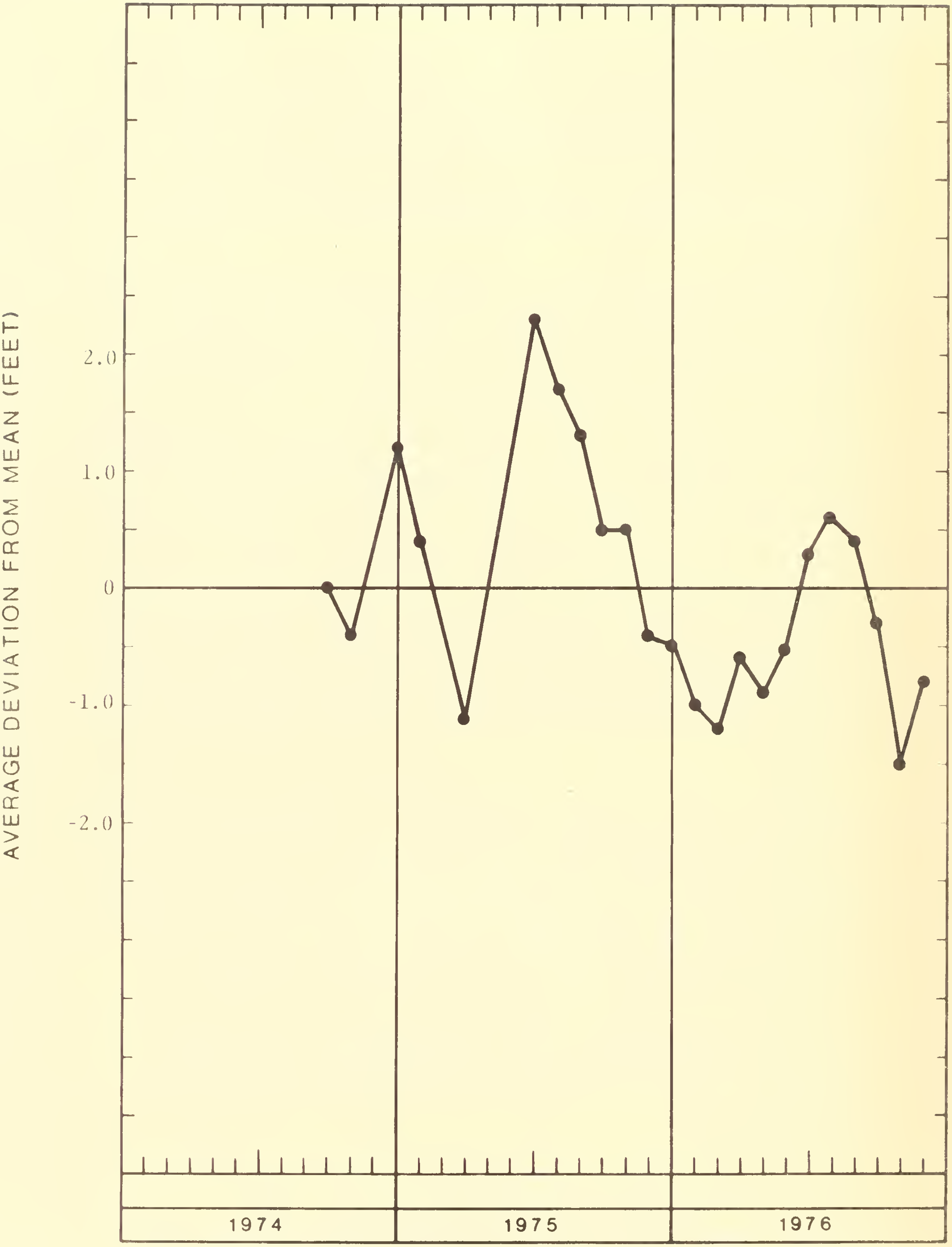


FIGURE 3-39 ALLUVIAL WELLS AVERAGE DEVIATION FROM MEAN

Table 3-43

AVERAGE DEVIATIONS FOR ALLUVIAL WELLS

Well No.	Average deviation from mean, feet	Saturated thickness for alluvium, feet	Average difference 1975-1976
A-1	1.7	65	-1.8
A-2	1.4	73	-2.4
A-3	1.7	37	-2.7
A-5	0.2	68	-0.2
A-6	2.6	27	+0.2
A-7	2.5	18	-1.7
A-8	1.2	47	+0.1
A-9	0.6	10	-0.5
A-10	2.3	24	-4.2
A-11	0.5	13	+0.7
A-12	0.7	28	+0.8

Table 3-44 WATER LEVELS IN UPPER AQUIFER WELLS

	Cb-2	Cb-4	AT-1C ST #3	SG-1 ST #2	SG-6 ST #3	SG-9 ST #2	SG-10A	SG-11 ST #3	SG-17 ST #2	SG-18A	SG-19	SG-20	SG-21
Ground Level	6737	7054	6905	6428	6888	6870	6950	6900	7036	7383			6811
M. P. Elevation	6737.0	7057.3	6906.0	6428.6	6890.7	6873.0	6953.6	6903.1	7038.6	7386.6	6384.4		6813.3
October 1974	6417.0	6616.0	6538.6			--		6544.0		--			
November 1974	6404.0	6619.2	6535.3			6523.9		--		6901.0			
December 1974	6398.9	6613.8	--			--		--		--			
June 1975	--	6626.9	--	6366.7	6548.9	6521.4	6572.2	6546.0	6638.5	6899.5		flowing	6699.9
July 1975	6414.0	6628.0	--	6367.5	6552.5	6522.2	6573.7	6549.2	6639.9	6901.0	flowing	"	6713.9
August 1975	6418.1	6629.0	6550.1	6367.4	6559.3	6522.2	6574.7		6640.9	6900.1	"	"	6703.3
September 1975	6415.8	6626.5	6548.1	6367.5	6558.6	6520.2	6573.5	6531.8	6638.5	6900.0	"	"	6702.9
October 1975	6405.8	6625.7	6548.4	6367.2	6557.5	6517.7	6572.7	6548.3	6640.1	6896.7	"	"	6703.7
November 1975	6406.9	6625.7	6549.0	6366.8	6559.0	6516.5	6574.0	6547.6	6640.5	6896.1	"	"	6703.9
December 1975	6408.8	6625.8	6547.0	6367.0	6559.3	6516.1	6573.2	6549.8	6639.4	6896.0	--	flowing	6703.8
January 1976	6408.3	6626.4	6548.8	6366.8	6556.5	6516.6	6572.5	6549.2	6639.8	6896.1	6379.0	"	6704.1
February 1976	6411.3	6627.1	6549.2	6364.4	6556.5	6520.2	6576.7	6548.9	6639.8	6896.0	6379.3	"	6703.7
March 1976	6412.5	6627.5	6549.4	6364.4	6556.1	6520.8	6574.5	6548.8	6639.7	6896.4	6380.1	"	6703.8
April 1976	6411.6	6627.3	6546.4	6364.4	6556.2	6520.2	6577.8	6548.5	6639.7	6897.0	6379.8	"	6703.9
May 1976	6413.2	6627.0	6549.8	6364.3	6558.9	6520.6	6578.0	6548.4	6640.8	6896.6	6380.3	"	6703.6
June 1976	6413.7	6632.9	6549.9	6364.0	6558.9	6520.9	6578.4	6548.1	6644.0	6901.5	6380.5	"	6705.7
July 1976	6413.4	6628.5	6549.0	6365.4	6559.1	6510.6	6578.9	6548.1	6641.3	6896.2	6381.4	"	6704.0
August 1976	6413.2	6628.4	6550.7	6365.4	6555.4	6510.6	6578.9	6548.2	6639.0	6896.2	flowing	"	6709.8
September 1976	6408.1	6628.1	6549.4	6365.4	6555.0	6511.0	6579.4	6548.1	6629.6	6895.6	"	"	6710.3
October 1976	6406.4	6632.7	6550.9	6365.8	6553.7	6522.2	6582.2	6548.5	6638.6	6896.5	6376.2	"	6705.2
Mean	6410.6	6626.1	6547.6	6365.9	6556.6	6518.6	6576.0	6547.2	6639.4	6897.7	6381.8		6705.0

found in the appendix. The average deviation from the mean for all upper aquifer wells is shown in Figure 3-40. At first glance this chart also seems to indicate a seasonal cycle with annual peaks similar to those seen for the alluvial wells. However, this appears to be only a coincidence caused by unusually high readings for a few wells. In the case of the alluvial wells, almost all the individual well records showed the June-July yearly peaks and the average shown in Figure 3-39 was representative of all wells in that respect. For the upper aquifer wells, however, that general pattern is not apparent in most of the individual well records. The mean values have been distorted by exceptionally high positive deviations for wells SG-21 and Cb-2 in 1975 and wells SG-18A and Cb-4 in 1976. Water level fluctuations should be related in some way to the precipitation and recharge cycle. However, because of the much greater distance from ground surface to water level in the upper aquifer wells as opposed to the alluvial wells, local increases in water level which might result from infiltration during the snowmelt period would not be expected to occur at the same time unless there were a direct hydraulic connection. It cannot be concluded from the data presented that a seasonal cycle has been confirmed in the upper aquifer.

A regional map of the potentiometric surface was prepared by the USGS, Figure 3-41. In the C-b area the potentiometric lines are approximately east-west in orientation and concave to the north. It is not possible to correlate all upper aquifer well levels with such a set of parallel lines. An approximate correlation of this type is shown by the solid lines in Figure 3-42. The gradient of the potentiometric surface is approximately 135 feet per mile to the north. As shown in the first Annual Summary Report, better matching curves on the Tract itself could be drawn concave downward, but these lines would not mesh with the regional trends. No simple set of potentiometric lines would adequately define all the well levels listed in Figure 3-42. One of the major incompatibilities is that between SG-6, String 3, and AT-1C, String 3. Although SG-6 is almost directly north (down-gradient) from AT-1C, the measured water level is approximately 10 feet higher. Interpreted literally, this would indicate a "mound" of water near the center of the Tract. This apparent condition has been used to infer the occurrence of infiltration from the surface with underground flow toward the surface drainages. A simpler explanation may be due to the small interval perforated in SG-6, String 3. This string is therefore recording the potential in only a small fraction of the highly stratified formation, whereas AT-1C will produce an average over a wider interval which reaches a considerably lower depth.

During the upper aquifer pump test, the horizontal permeability in the direction from AT-1 to SG-11 was estimated to be nine times as great as that from AT-1 to SG-6. This behavior tends to confirm the presence of an anomalous structural condition between AT-1C and SG-6. A potentiometric pattern which meshes with the regional trends, yet follows the observed well levels on-Tract and suggests a stratiographic deviation between AT-1C and SG-6 is given by the dashed line

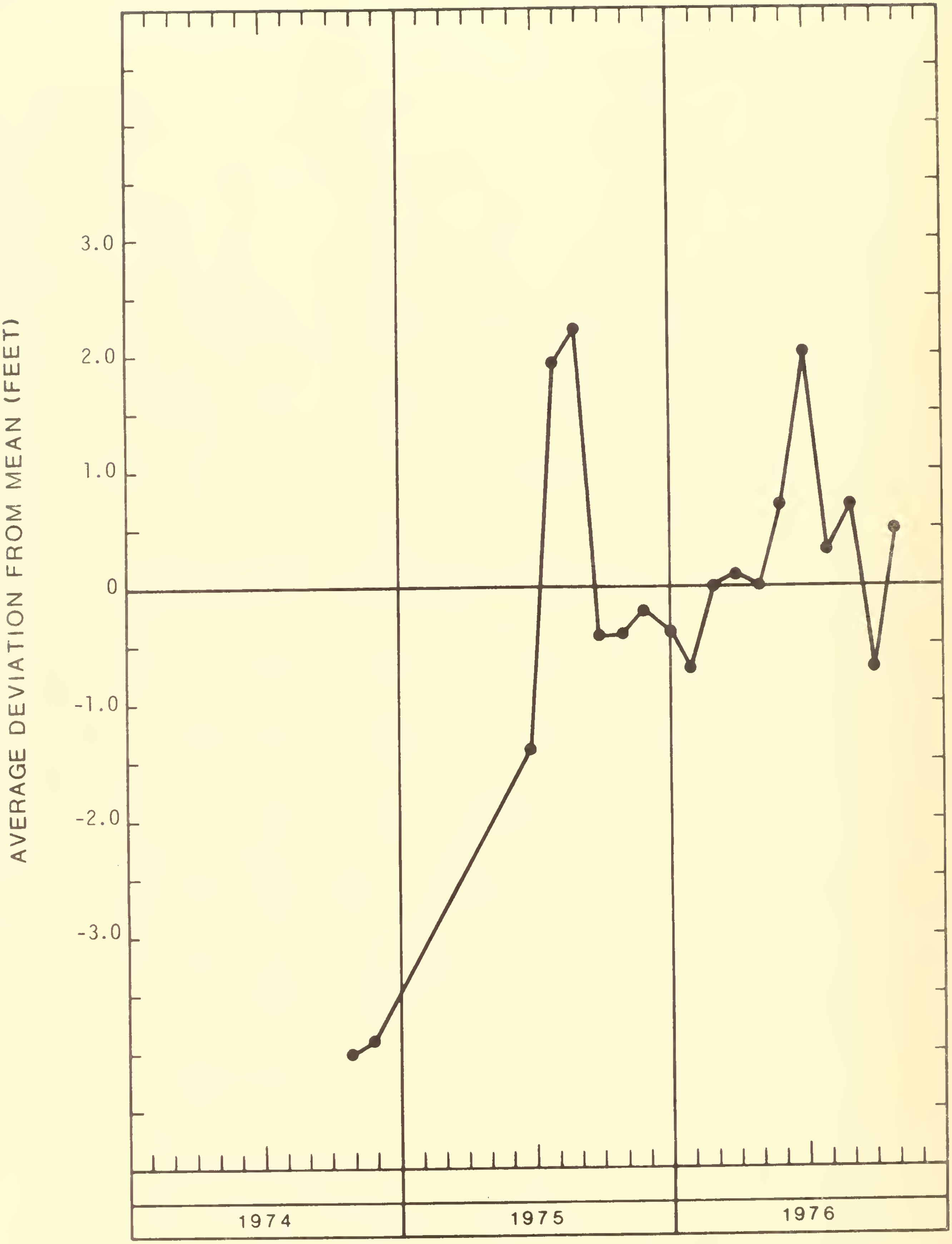
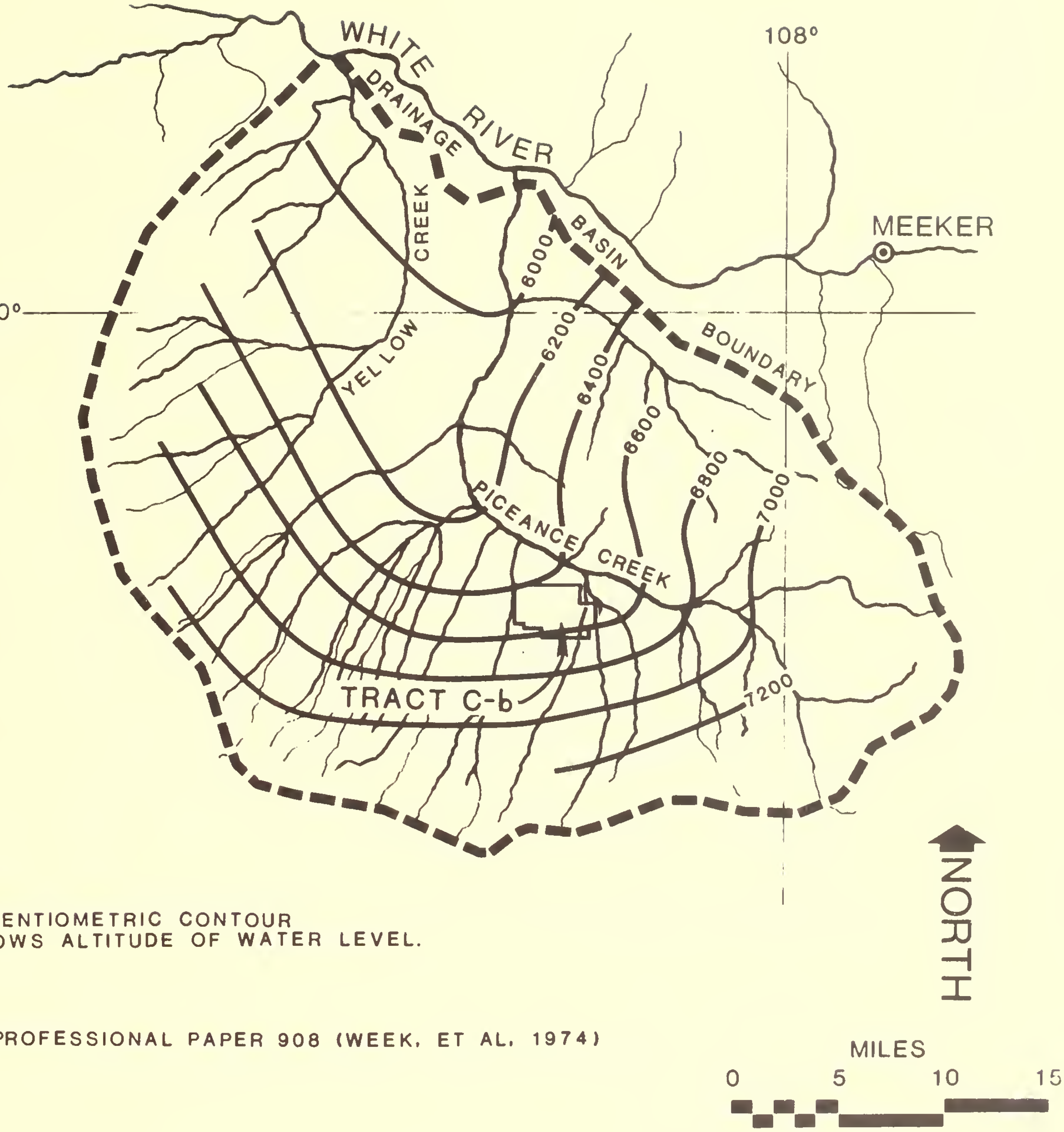


FIGURE 3-40

UPPER AQUIFER WELLS
AVERAGE DEVIATION FROM MEAN



——6200—— POTENTIOMETRIC CONTOUR
SHOWS ALTITUDE OF WATER LEVEL.

SOURCE: USGS PROFESSIONAL PAPER 908 (WEEK, ET AL, 1974)

FIGURE 3-41 USGS POTENTIOMETRIC MAP BASED ON WATER LEVELS IN WELLS OPEN TO BOTH THE UPPER AND THE LOWER AQUIFERS, APRIL 1974

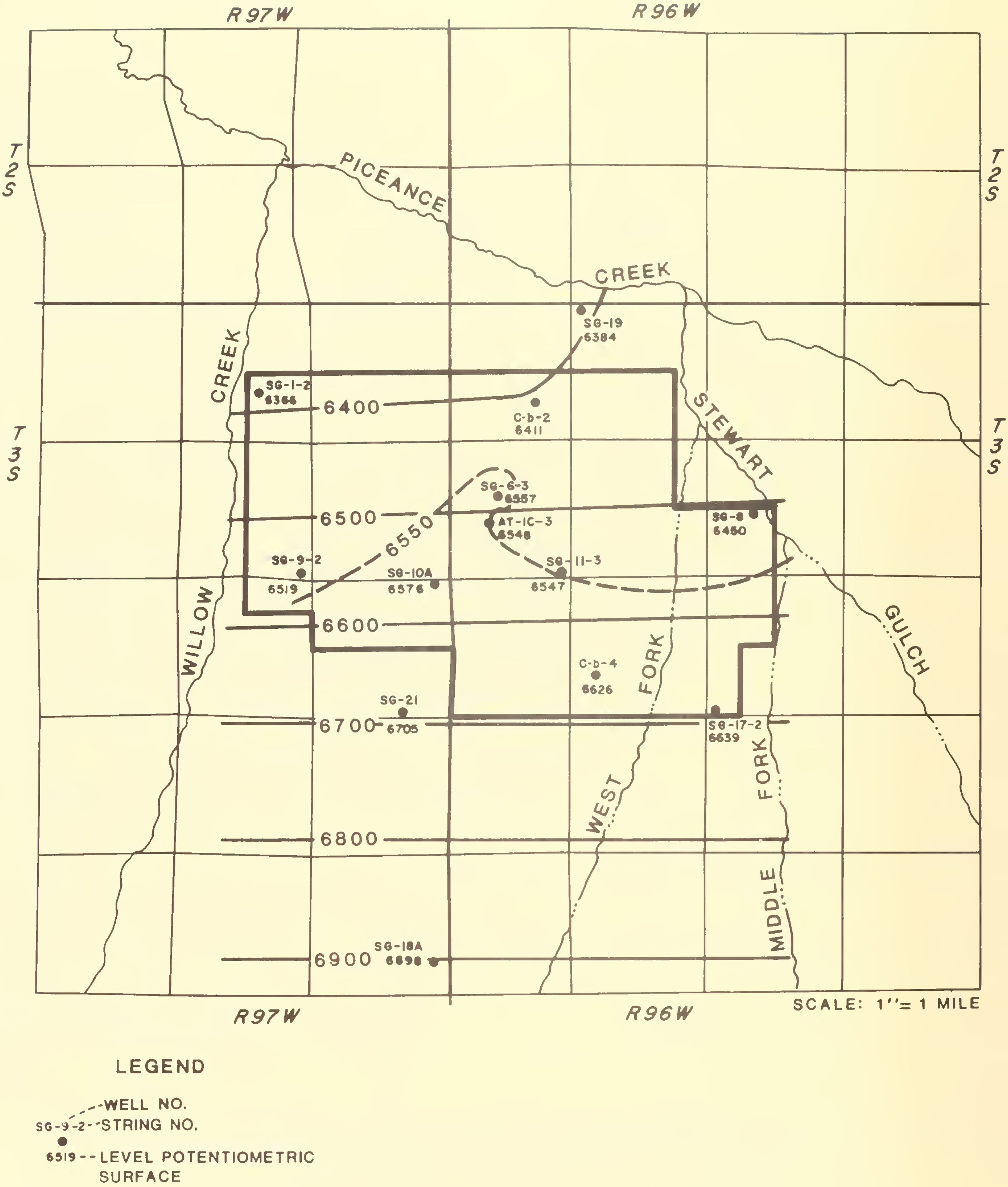


FIGURE 3-42 POTENTIOMETRIC SURFACE - UPPER AQUIFER

for 6550 feet in Figure 3-42. Considerably more data would be required to actually define such a strong non-conformity.

3.2.2.5.3 Lower Aquifer Wells

Reduced water level data, as elevations above sea level are given in Table 3-45. Complete charts for individual wells may be found in the appendix. The month-by-month average deviation from the mean for all lower aquifer wells is shown in Figure 3-43. The large positive deviation for July 1975 is due to a single well reading on SG-9, String 1, which is 10 feet higher than would be expected by the trend on the well chart. It is reasonable to assume that an error was made in recording the 10 foot marker on the sounder cable. If this reading is eliminated from the data, then the steady upward trend of lower aquifer water levels becomes even more marked. This upward trend is most emphatic for those wells close to the aquifer test site, and the behavior of these wells tends to dominate the average. It is possible that these wells continue to show some recovery from the aquifer depletion which occurred during the aquifer pump test. The rate of change is much larger than would be expected after several months of elapsed time, however, and continues at an approximately constant rate instead of showing a logarithmic slowing as would result from a one-time depletion followed by recovery. A more likely explanation may be the effect of open core holes in the vicinity--to be discussed in a later section.

Potentiometric gradients for the lower aquifer generally parallel those for the upper aquifer, and may be represented approximately as shown in Figure 3-44. Throughout the Tract the upper aquifer always has a higher head than the lower. Those wells which have separate tubing strings completed in each of the aquifers are listed in Table 3-46 along with the water levels in each aquifer and the difference between them at that point. The differences are plotted in Figure 3-45. Since the difference (upper-lower) is always positive, it indicates that vertical water flow, if any, across the Mahogany zone is always downward under the Tract. Figure 3-45 illustrates again the "water hill" which appears in the middle of the Tract for the upper aquifer. As mentioned before, this could be the result of infiltrating precipitation if the Willow Creek, Piceance Creek, and Stewart Gulch drainages are coincident with increased Mahogany zone permeabilities or fractures. Differences in potentiometric level between the two aquifers would then tend to disappear as the creeks are approached.

The three triple-completion wells on Tract each have one tubing string perforated only within the Mahogany zone. A comparison between the Mahogany zone strings and the corresponding deep strings in Table 3-47 shows that head continues to decrease with depth in the lower aquifer.

Table 3-45 WATER LEVELS IN LOWER AQUIFER WELLS

	Cb-1	AT-1C ST #1	AT-1C ST #2	SG-1 ST #1	SG-8 SG-8R	SG-10 SG-10R	SG-11 ST #1R	SG-11 ST #2	SG-17 ST #1R	SG-9 ST #1	SG-6 ST #1	SG-6 ST #2	AT-1
Ground Level	6760	6905	6905	6428	6538	6950	6900	6900	7036	6870	6888	6888	6909
M.P. Elevation	6763.4	6906.0	6906.0	6428.8	6540.8	6952.5	6903.1	6903.1	7038.6	6873.0	6890.7	6890.7	6911.6
September 1974		6506.5	6510.0					6530.6					
October 1974		6508.9	6513.0							6505.6			
November 1974													
June 1975	6406.8				6450.1	6526.2		6525.0		6507.4	6487.1		
July 1975	6505.5				6453.0	6527.2				6521.0	6490.1		
August 1975	6406.1	6508.8	6510.4	6364.3	6450.5	6487.6				6511.0	6489.9	6504.1	
September 1975	6403.7	6510.1	6511.0	6365.1	--	6484.0				6509.2	6489.0	6505.3	6511.8
October 1975	6404.0	6512.9	6513.8	6366.0	6450.9	6480.0		6532.9		6509.3	6491.0	6507.9	6512.6
November 1975	6404.1	6515.6	6516.5	6362.6	6451.6	6480.2		6534.8	6625.6	6508.5	6492.5	6510.4	6516.0
December 1975	6403.6	6515.4	6517.0	6363.1	--	6535.4	--	6538.9	6624.7	6508.1	6491.9	6510.2	6514.2
January 1976	6404.6	6517.8	6518.4	6367.0	6527.8	6535.6	6499.0	6539.8	6625.1	6508.0	6493.1	6512.6	6514.2
February 1976	6403.8	6518.8	6519.4	6365.6	6528.0	6536.8	6489.3	6537.8	6625.3	6510.6	6493.6	6513.3	6518.7
March 1976	6404.0	6517.2	6519.5	6365.6	6523.6	6537.5	6489.2	6537.8	6624.8	6510.7	6493.6	6513.2	6519.0
April 1976	6403.8	6520.0	6520.5	6364.6	6522.0	6537.5	6489.2	6537.7	6624.9	6510.9	6493.8	6514.1	6519.1
May 1976	6404.1	6519.6	6520.3	6364.3	6528.4	6537.9	6489.2	6537.6	6628.5	6510.9	6493.9	6514.2	6519.0
June 1976	6404.3	6520.8	6520.6	6360.7	flowing	6538.3	6489.2	6537.2	6634.2	6511.7	6494.2	6514.4	6519.6
July 1976	6403.9	6520.4	6520.7	6359.0	"	6538.2	6489.2	6537.3	6631.4	plugged	6495.1	6514.5	6519.7
August 1976	6403.9	6520.4	6520.7	6359.0	"	6540.2	6492.2	6540.7	6629.3	"	6495.4	6515.6	6519.7
September 1976	6405.8	6520.4	6520.6	6359.3	"	6538.4	6492.2	6540.7	6641.6	"	6495.4	6515.6	6519.7
October 1976	6406.4	6524.8	6523.3	6359.0	"	6542.5	6497.4	6544.3	6630.7	6511.0	6496.4	6514.2	
Mean	6404.6	6516.4	6517.4	6363.0	6532.0	6538.0	6491.6	6536.9	6628.8	6510.3	6492.7	6512.0	6517.2

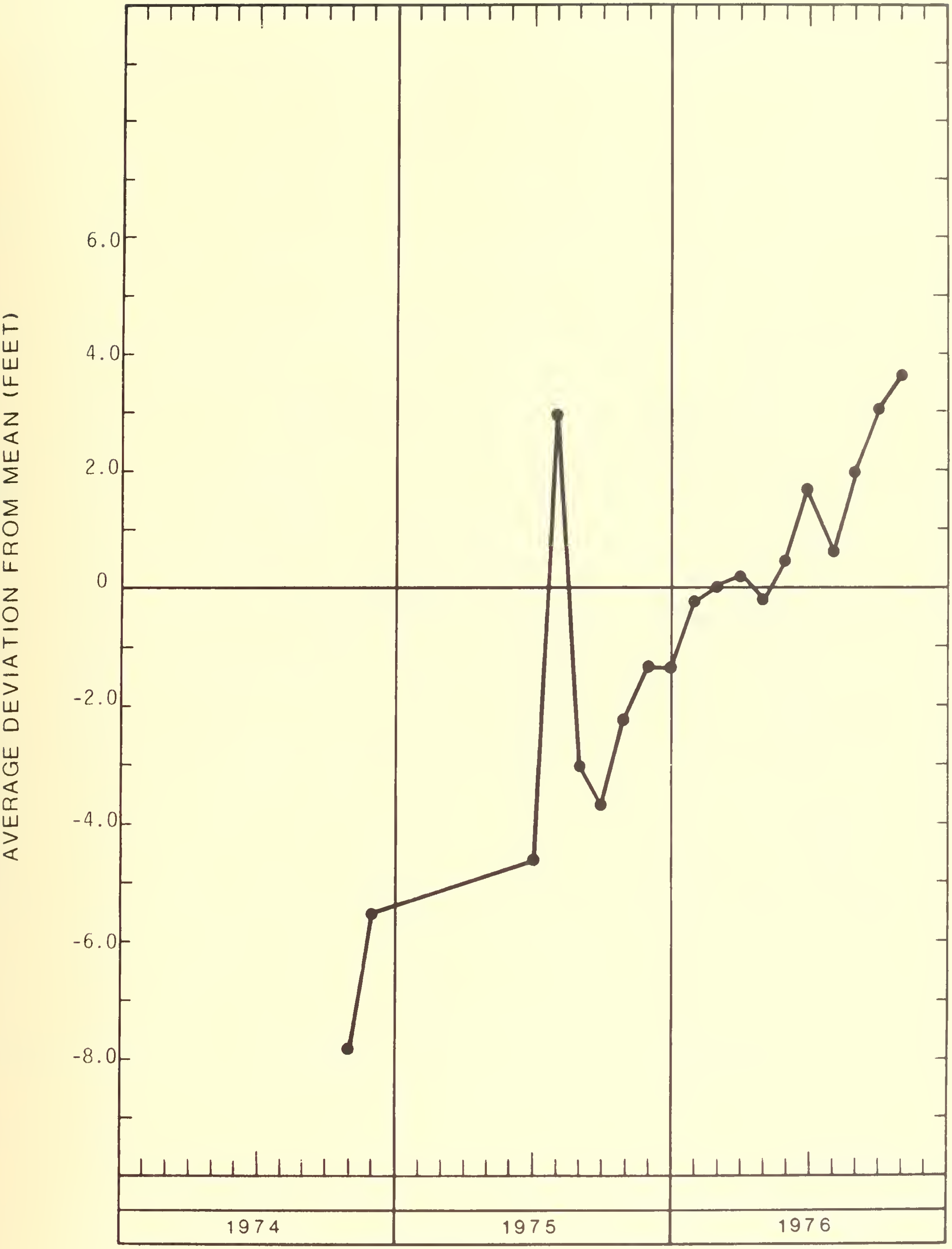


FIGURE 3-43 LOWER AQUIFER WELLS AVERAGE DEVIATION FROM MEAN

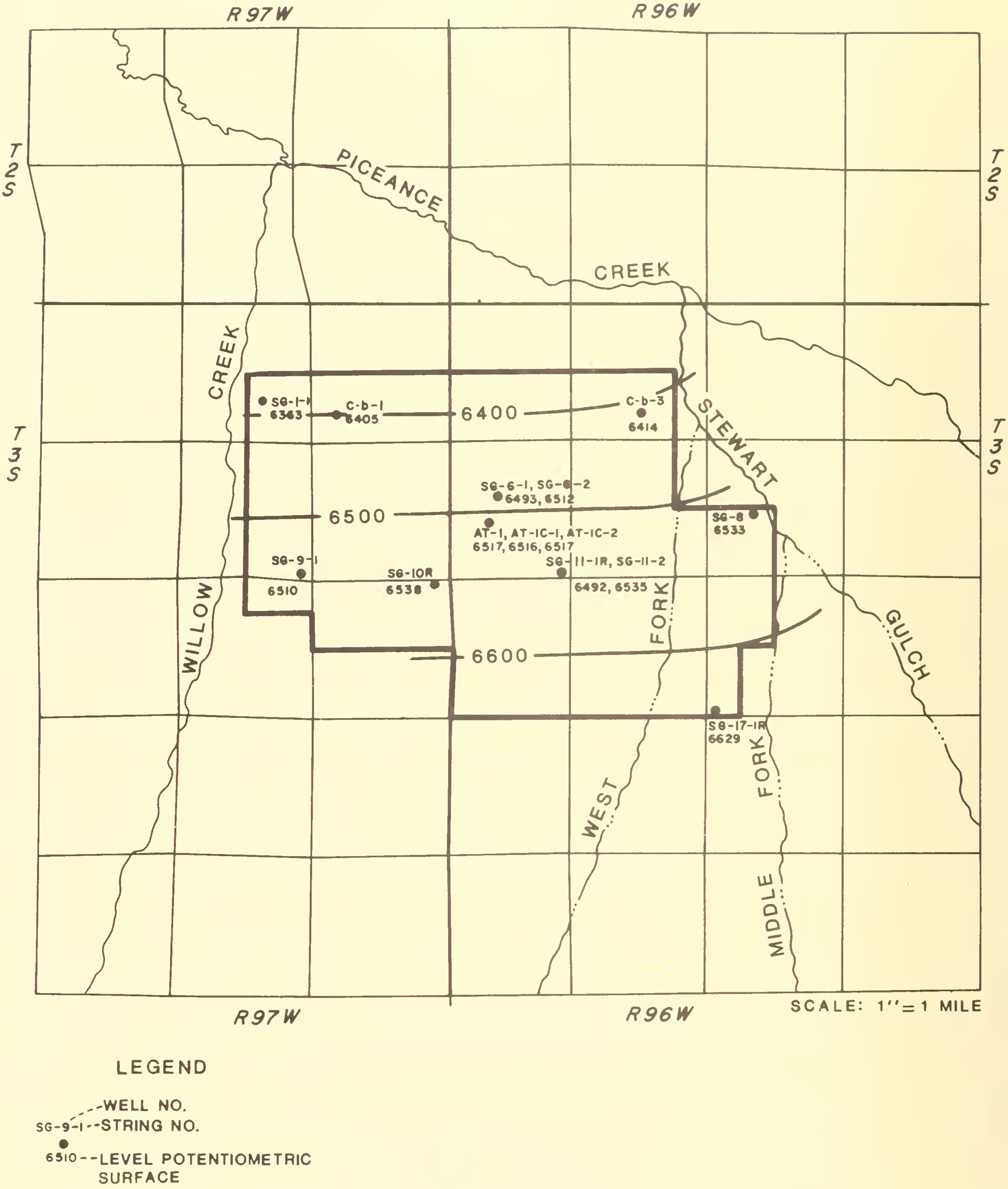


FIGURE 3-44 POTENTIOMETRIC SURFACE - LOWER AQUIFER

Table 3-46 WATER LEVEL DIFFERENCES ACROSS THE MAHOGANY ZONE

Well	Upper Aquifer Strings	Lower Aquifer Strings	Difference Upper-Lower
AT-1C	6547.6	6517.4	+ 30.2
AT-1C		6516.4	+ 31.2
SG-1	6365.9	6363.0	+ 2.9
SG-10R, SG-10A	6576.0	6538.0	+ 38.0
SG-11	6547.2	6491.6	+ 55.6
SG-11		6536.9	+ 10.3
SG-17	6639.4	6628.8	+ 10.6
SG-9	6518.6	6510.3	+ 8.3
SG-6	6556.6	6492.7	+ 63.9
		6512.0	+ 44.6
		Average	+ 30.0

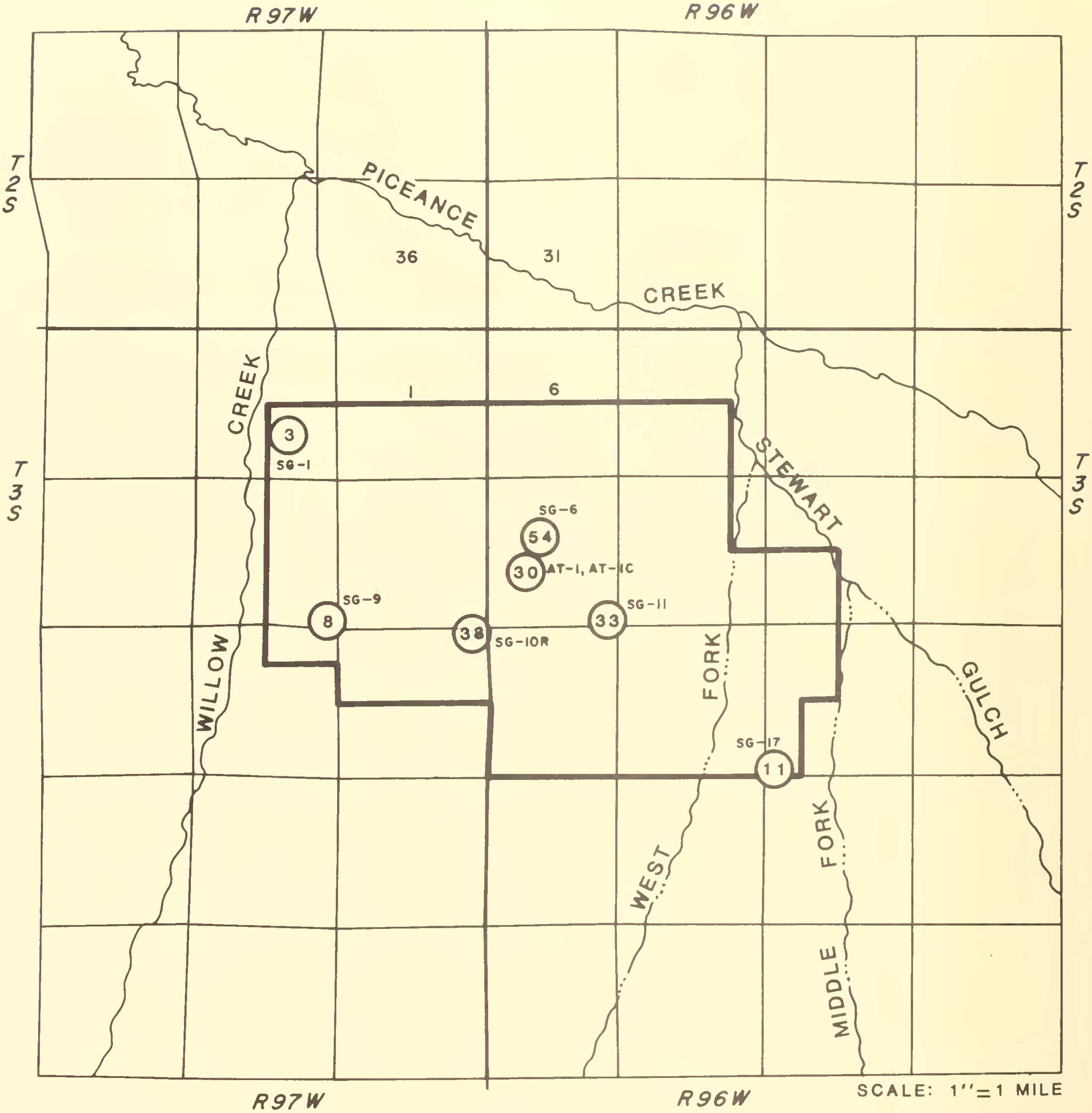


FIGURE 3-45 DIFFERENCE IN POTENTIOMETRIC SURFACES ACROSS THE MAHOGANY ZONE

Table 3-47 EFFECT OF DEPTH BELOW MAHOGANY ZONE

Well	String	Bottom of Perforations	Water Level
AT-1C	#2	M-zone	6517
	#1	1646 feet	6516
SG-6	#2	M-zone	6512
	#1	2220 feet	6493
SG-11	#2	M-zone	6537
	#1	1928 feet	6492

3.2.2.5.4 Effect of Open Holes

The generally decreasing head with depth, discussed above, will result in down-hole flow, from the upper aquifer to the lower, in any well which is left open to the formation in both zones. However, at a depth of approximately 2000 feet in some wells a thin (50 feet) water-bearing lens was encountered which exhibited a high hydrostatic head along with very poor quality water (TDS greater than 30,000 mg/1). In order to prevent this low quality water from migrating up the well holes and comingling with the better-quality water in the overlying aquifers, four wells were recompleted in order to block off this deep saline zone. The lower portion of the deep tubing strings in SG-10, SG-11, and SG-17 were plugged with cement and the open hole SG-8 was plugged similarly. After recompletion, the water level increased notably in SG-8, which became a flowing artesian well. (Figure A-33, in the appendix.)

In addition to the wells drilled under the C-b lease, there are a number of open coreholes on or in the vicinity of the Tract which were left by pre-lease exploratory activities. The observed consistent rise in lower aquifer water levels prompted an examination as to whether this rise could be due to interaquifer flow via the open holes. Holes which could have been influencing water levels on the Tract include Cb-3, TG-71-1, TG-71-2, TG-71-3, TG-2-1, and Federal 2b. The locations of these wells are shown in Figure 3-46.

Open hole effects may be estimated by reference to Figure 3-47 which represents the aquifers observed on C-b. Well W_1 is completed with communication to only the upper aquifer. The water level observed in this well will be H_1. The casing in well W_2 is perforated only in the lower aquifer and the observed water level is H_2. A well such as W_3, open to both aquifers simultaneously, will exhibit an intermediate level, given by H_3. H_3 may be calculated as $(H_1 T_1 + H_2 T_2)/(T_1 + T_2)$ where T_1 and T_2 are the transmissivities of the respective aquifers. As soon as well W_3 is completed, water will begin to flow through the well bore from the upper aquifer to the lower and level H_3 will be reached almost immediately. At horizontal distances from W_3, the water level in the upper aquifer will decrease with time and the water level in the lower aquifer will rise. As time increases H_1 and H_2 will approach H_3 (ignoring recharge). Water levels in the upper and lower aquifers, wells W_1 and W_2, will therefore be a function of time and radial distance from any open well such as W_3.

To estimate the amount of bias which might result, the applicable differential equation was solved and the results tabulated in Table 3-48. It was assumed that the original difference Δ between H_1 and H_2 was 25 feet. As can be seen in the table, water levels near any open core holes could be affected significantly in a period of one or two years. Although the effects are not directly additive, an observation well within the radius of influence of more than one open hole will exhibit even larger effects than those tabulated for a single well. Several open wells on and near C-b have been within the time and distance

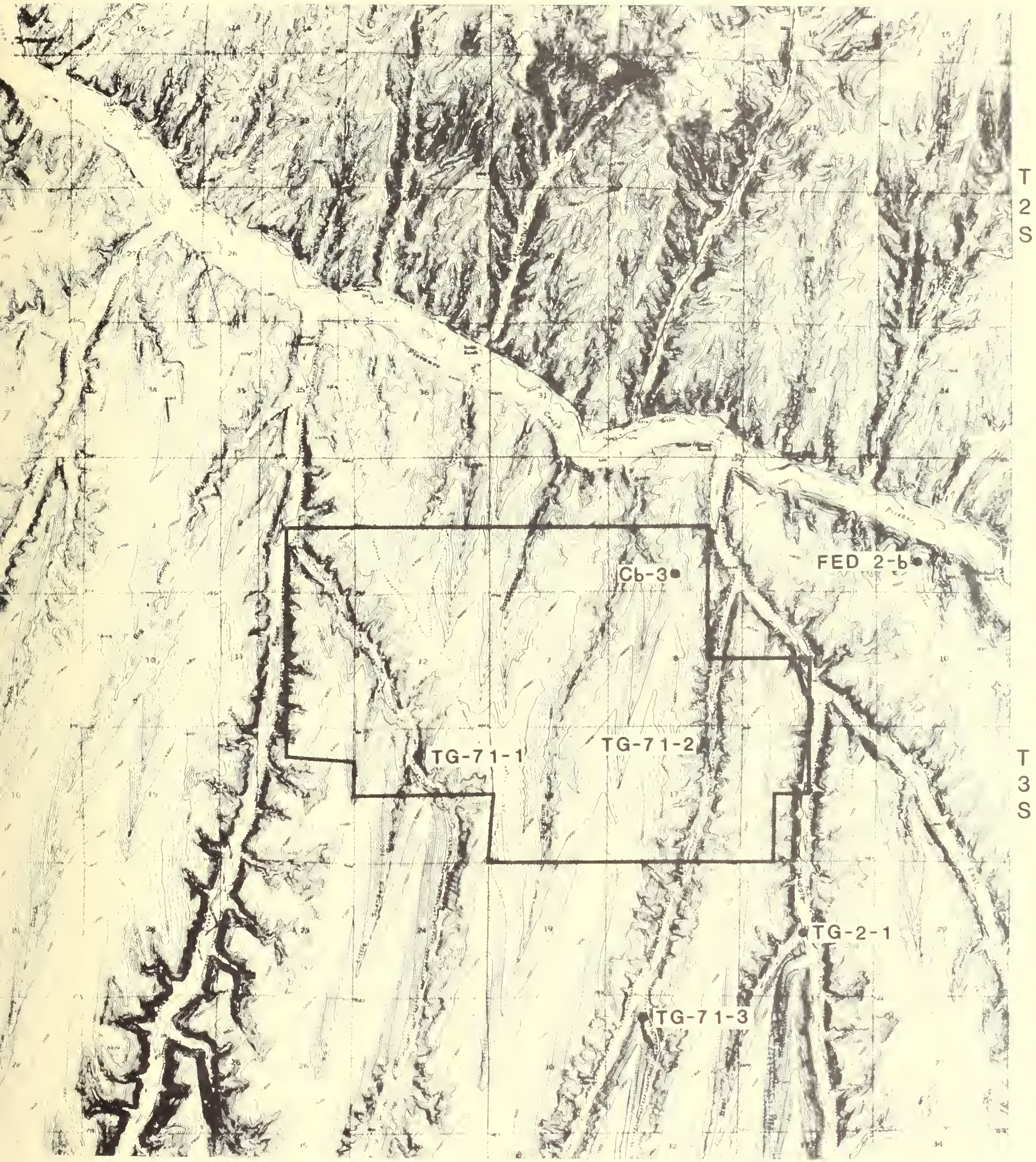


FIGURE 3-46 LOCATION OF PRE-LEASE OPEN CORE HOLES ON AND NEAR TRACT C-b

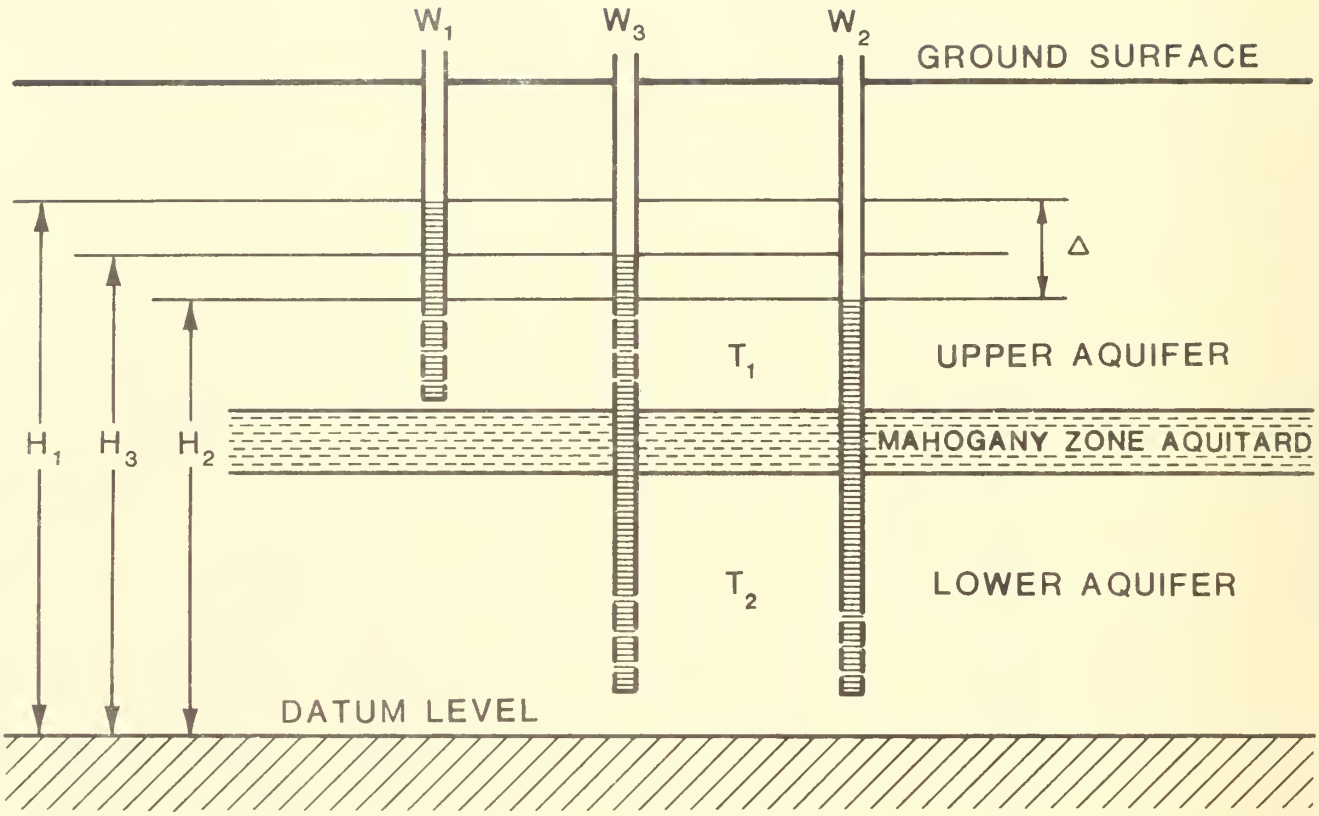


FIGURE 3-47 GENERALIZED CROSS SECTION OF C-b TRACT AREA

Table 3-48 EFFECT OF OPEN (TO BOTH AQUIFERS) WELLS ON WATER LEVEL ELEVATIONS

Upper Aquifer Fall in Feet

Time in Days / Radial Distance in Feet	0	150	750	1500	7500
0	5.00	5.00	5.00	5.00	5.00
500	0	1.35	1.68	1.77	2.03
1000	0	0.99	1.13	1.45	1.71
2000	0	0.64	0.99	1.13	1.40
5000	0	0.23	0.55	0.69	1.01
10000	0	0.04	0.26	0.39	0.69

Lower Aquifer Rise in Feet

Time in Days / Radial Distance in Feet	0	150	750	1500	7500
0	20.0	20.0	20.0	20.0	20.0
500	0	5.38	6.70	7.06	8.10
1000	0	3.94	5.32	5.80	6.84
2000	0	2.54	3.96	4.50	5.60
5000	0	0.90	2.20	2.76	4.02
10000	0	0.15	1.04	1.54	2.78

envelopes to have caused measurable changes on the Tract. In the summer of 1976, the USGS undertook a remedial program to rework such open holes and close off communication between the two aquifers. Any detailed model to predict future water levels based on water-level observations to date would have to consider the history of these wells and their influence on the relative aquifer levels.

3.2.2.5.5 Barometric Effects

The continuous water level monitors are capable of detecting minute changes in water level due to fluctuations in the atmospheric pressure. If a confined aquifer is penetrated by a well, the water level in the well will respond to barometric changes, as the air pressure forces water into and out of the confined interval. A change in air pressure above an unconfined aquifer should have no effect on the water level in a well.

Figure 3-48 presents the water level recorded in well AT-1 and the barometric pressure at air quality trailer 023 for approximately three weeks in April 1976. Readings are plotted at 6-hour intervals and show an obvious strong correlation between the two curves. The data were presented earlier as Figure 3-38 using only daily averages and showing barometric pressure as feet of water column. At that scale, every maximum and every minimum are correlated between the two curves. With both curves plotted to the same vertical scale, it is seen that a barometric change of one foot of water pressure causes a change in well level of somewhat less than one foot. The ratio of the two is termed the barometric efficiency. A completely confined and completely elastic aquifer would show an efficiency of 100 percent. A lower aquifer well, such as AT-1, would be most likely to exhibit artesian or confined aquifer behavior with a high barometric efficiency. Figure 3-49 shows that the aquifer above the Mahogany zone, as represented by well SG-17, String #2, also exhibits a high barometric efficiency. This is a result of the geologic stratification and low vertical permeability in those rich oil shale zones above the Mahogany zone.

In contrast to the behavior in the deep, confined aquifers, barometric pressure has no effect on wells in the unconfined alluvial aquifers. Figure 3-50 compares the water level record for alluvial well A-8 against barometric pressure for the month of April. As expected, no barometric effects are seen.

3.2.3 Water Quality in Wells

3.2.3.1 Rationale for Measurement

Water quality measurements in wells provide information concerning the suitability of ground water for various uses, serve as indicators of change in quality, and also can be used to study the effects

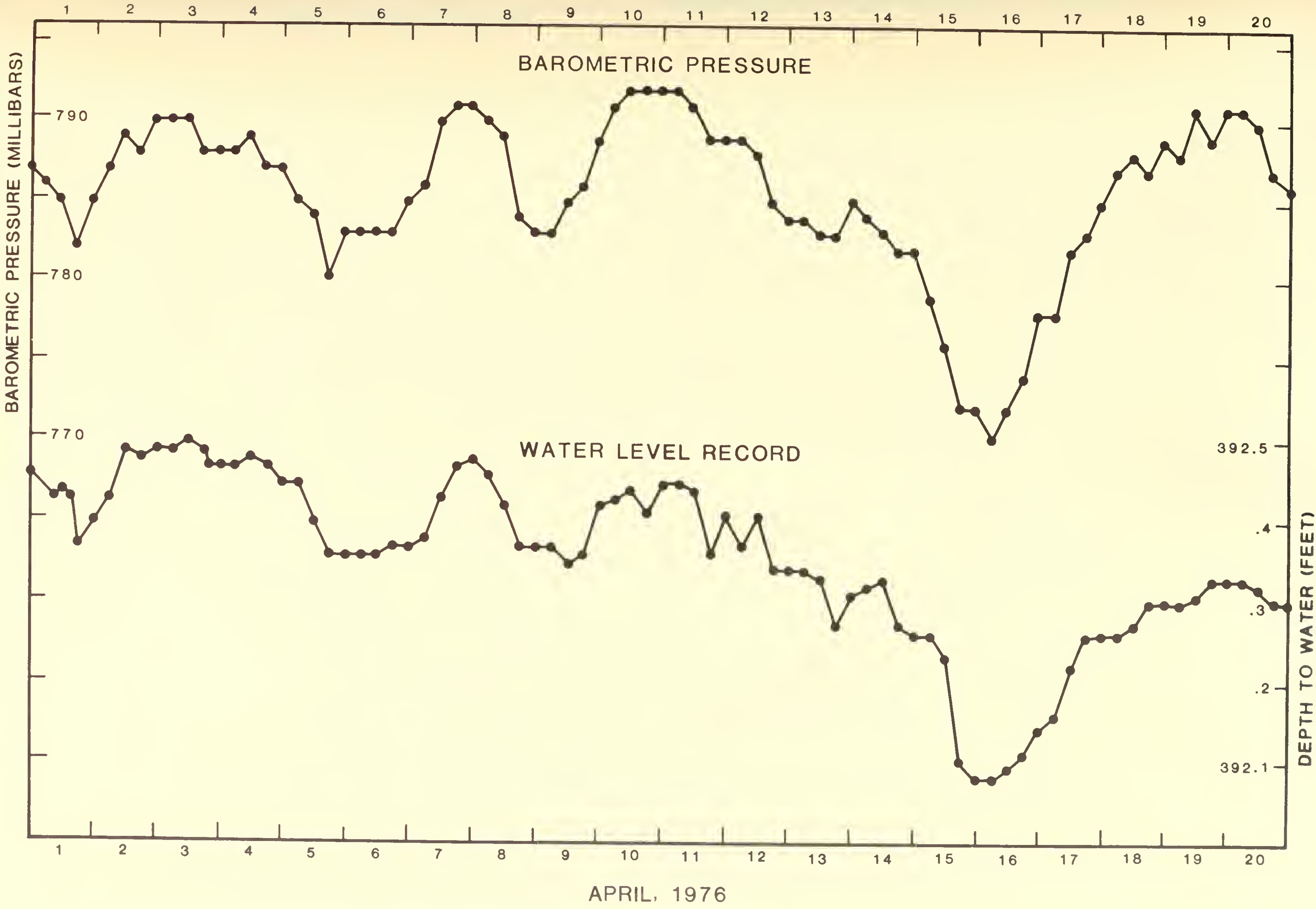


FIGURE 3-48 CORRELATION BETWEEN BAROMETRIC PRESSURE AND WATER LEVELS IN WELL AT-1

FIGURE 3-49 **WELL SG-17-2**

FEBRUARY, 1976

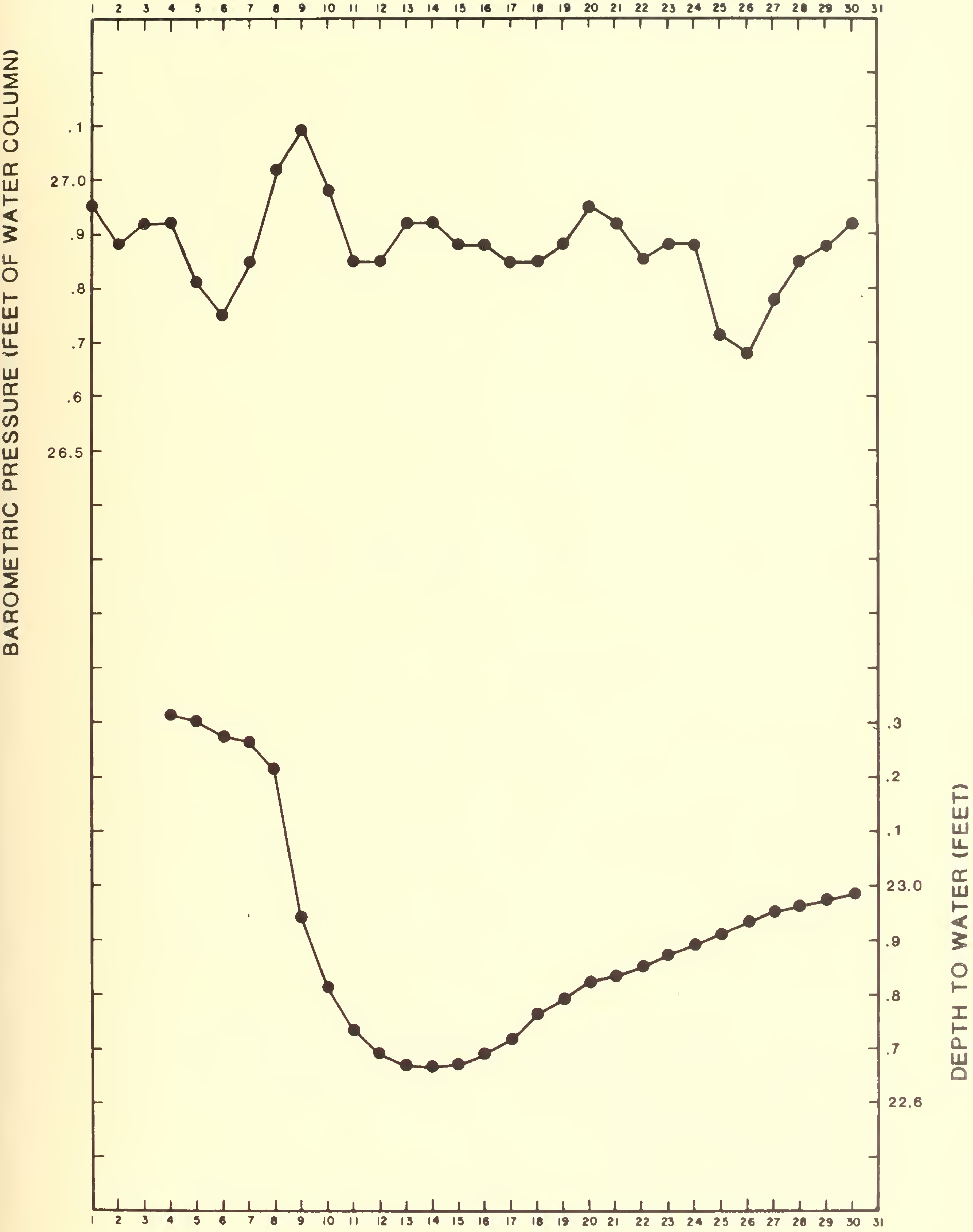


FIGURE 3-50 WELL A-8

SEPTEMBER, 1976

of changes in ground water flow. The many complex factors that influence the composition of ground water make it impossible to predict quality changes without a detailed study of natural conditions. The chemical composition of natural water is derived from many different sources of solutes, including gases and aerosols from the atmosphere, weathering and erosion of rocks and soil, and solution or precipitation reactions underground. Effects produced by man's activities are then superimposed on the others. The ways in which solutes are taken up or precipitated and the amounts present in solution are influenced by many environmental factors, including climate, structure, position and composition of rock strata, and biochemical effects associated with the life cycles of plants and animals. Various requirements are known and postulated for water to be used in domestic, agricultural, or industrial uses, as well as for maintenance of existing flora and fauna. A rational water management program cannot be devised without a comprehensive water quality inventory.

3.2.3.2 Objectives

Objectives of this task were to determine the major and trace constituents present in the ground water of the alluvial aquifers and deep aquifers near the mining zone, and to estimate the variability as functions of time and space.

3.2.3.3 Experimental Design

Locations of both the alluvial and deep wells have been discussed in earlier sections. With locations fixed, the major experimental design variable left is frequency of sampling. Both alluvial and deep wells were sampled at 6-month intervals for the first year. Because of the slow rate of change in the deep aquifers and the possibility of more rapid changes in the alluvium, sampling frequency for the deep wells was decreased during the second year while selected alluvial wells were sampled more frequently. The selected alluvial wells were sampled in February, April, May, June, July, August, September, and October of 1976. The original schedule was planned for the last sample to be taken in November instead of October, but in order to be able to include that data in this two-year baseline report, the sampling date was moved up by one month.

In the deep aquifers, water compositions show greater variations with depth than with geographical location. Interpretation of water quality data must therefore consider the interval being sampled. For simplicity, all the deep monitoring wells have been divided into Upper Aquifer Wells (Mahogany zone and above) and Lower Aquifer Wells (below the Mahogany zone). Locations of the various core holes, observation wells and test wells were given in Figure 2-2. The well depths and completions are presented in Figures 3-51 and 3-52 as they relate to the Tract stratigraphy. Several of the wells have multiple tubing strings, perforated in different zones. Those

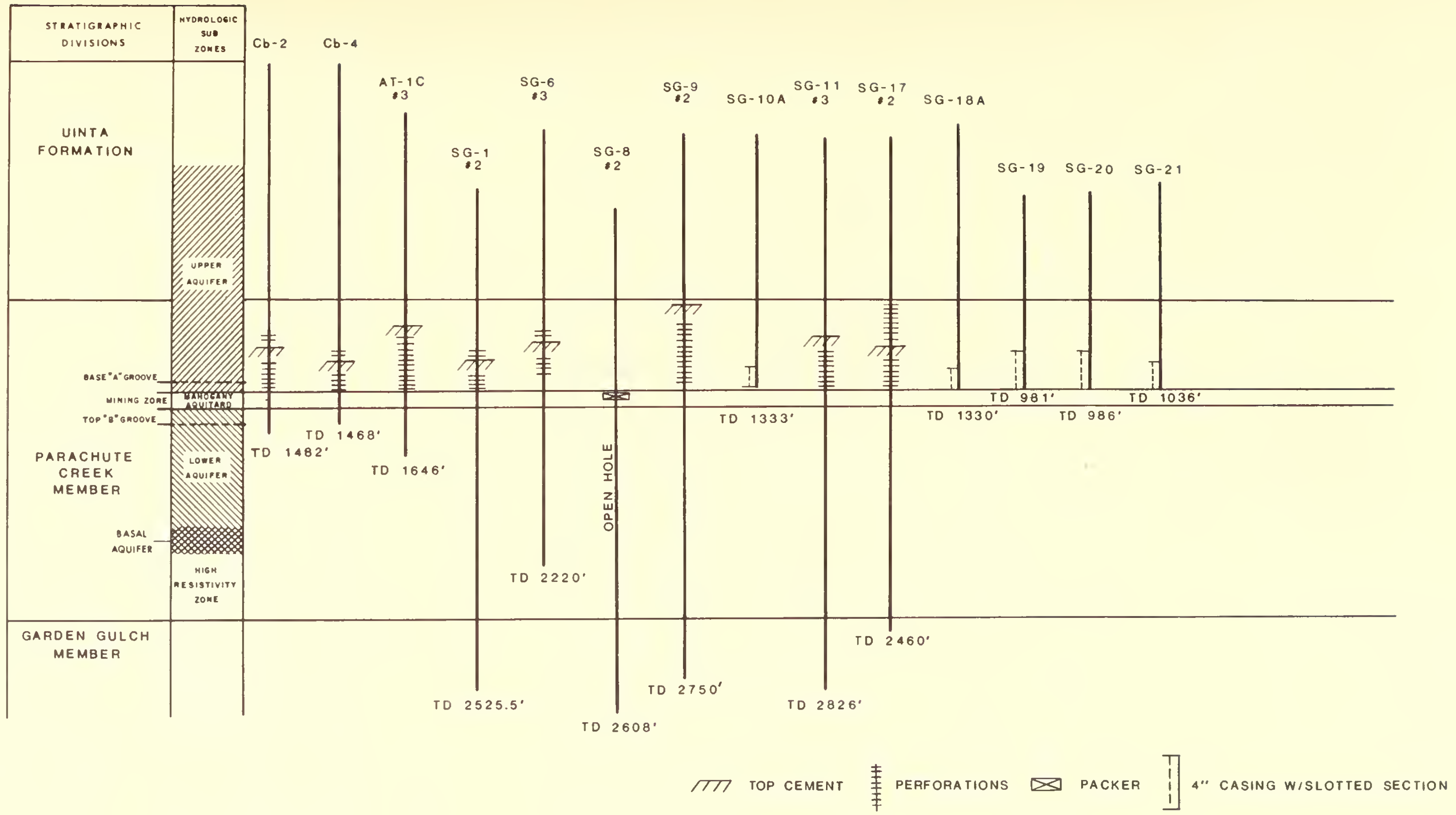


FIGURE 3-51 WELL COMPLETIONS IN THE UPPER AQUIFER

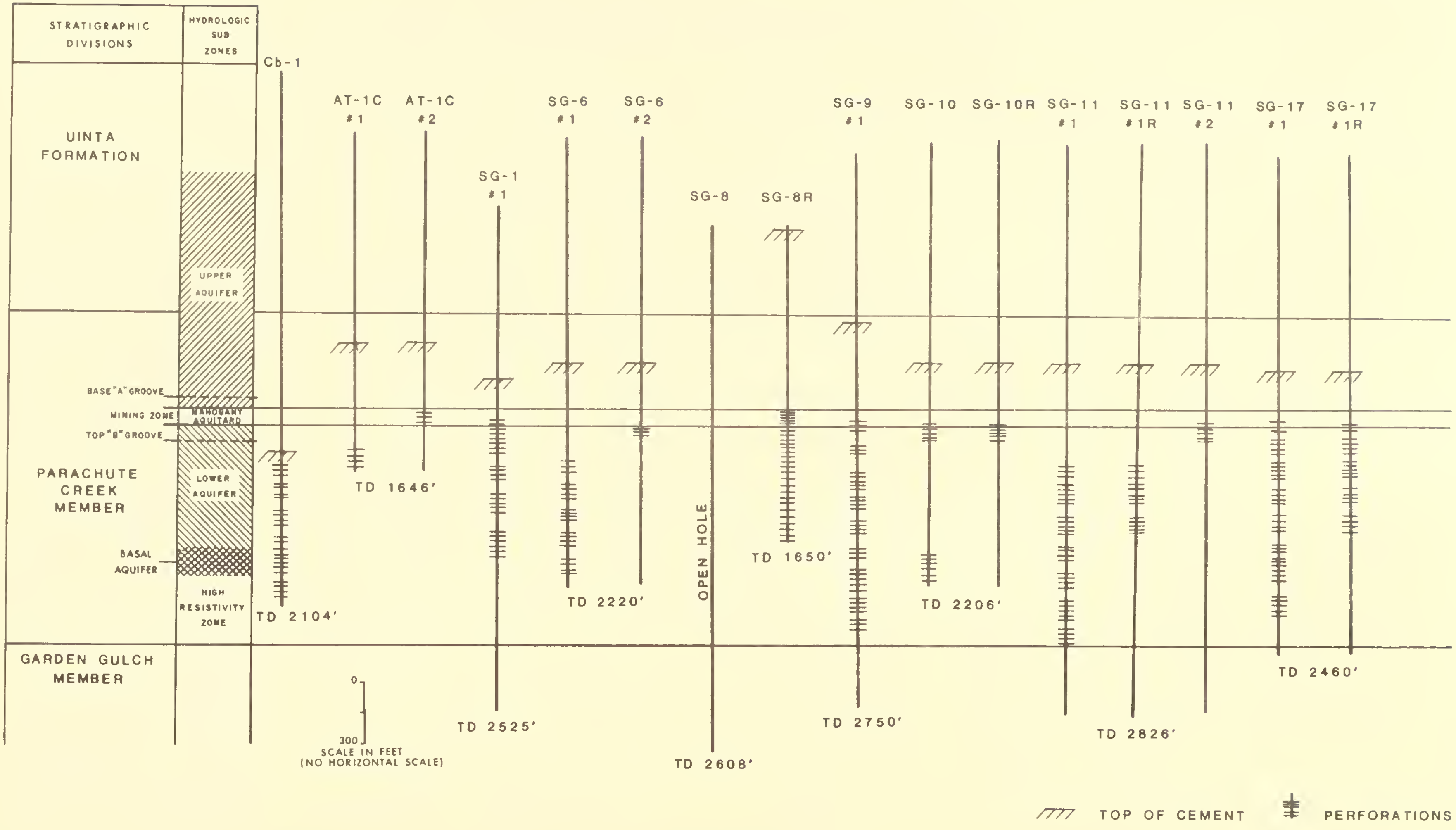


FIGURE 3-52 WELL COMPLETIONS IN THE LOWER AQUIFER

strings completed in the upper aquifer are shown in Figure 3-51 and those open to the lower aquifer are shown in Figure 3-52. Wells SG-8, SG-10, SG-11, and SG-17 were reworked in September 1975 to seal off their lowest portions, which had penetrated a thin, highly saline water zone. Reworked tubing strings are designated by a Suffix R.

3.2.3.4 Methodology

Alluvial wells were sampled by pumping directly from the well. A submersible electric pump was lowered into the well on a cable and pumped water to the surface through a garden hose. Pumping was continued for one hour, with water temperature and conductivity being recorded periodically. A five-gallon sample was then collected in a polyethylene carboy. The sample was filtered in the field under nitrogen pressure and placed in bottles prepared for the various analyses required.

Direct pumping from the deep wells was not possible because of the great depth to water and the small size (2-3/8") tubing used in the wells. A swabbing rig was used to obtain samples from these wells. A set of rubber cups (swabs) of the same diameter as the well tubing on a length of steel rod is lowered down by a 3/4" steel cable. One-way lips on the cups allow them to descend through the water, but when pulled up rapidly they force water ahead of them to the surface. This cyclic pumping operation was usually continued for a period of three hours before collecting a sample. Sample collection procedures were identical to those used for the alluvial wells. The amount of water brought to the surface on each swabbing run was measured by passing the water through a flowmeter before discharging it to the surface.

3.2.3.5 Results and Discussion

3.2.3.5.1 Alluvial Wells

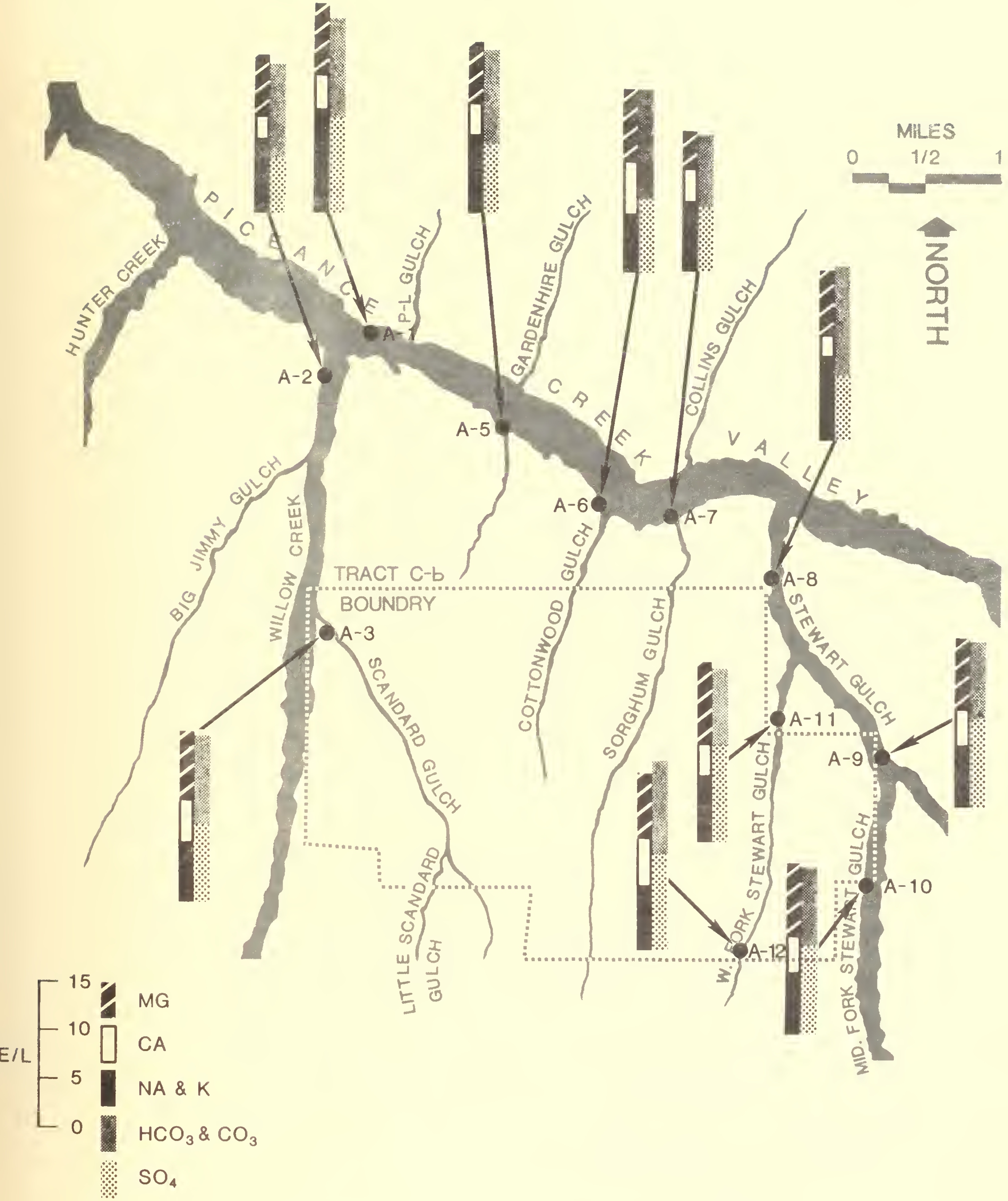
A complete listing of the water quality data for alluvial wells is given in the appendix, Tables A-11 through A-16. Mean values for the major ionic constituents for each well are given in Table 3-49. These data are plotted in the form of Collins diagrams in Figure 3-53. The chemical analyses show a marked similarity to the results for the springs and seeps. While Weeks, et al. (1974) classify the alluvium water in the Piceance Basin as sodium bicarbonate type, the water in the alluvium near Tract C-b is a mixed type. Sulfate levels are approximately equal to bicarbonate levels.

The concentration of dissolved solids averages 1000 mg/l with a range of 700 to 1300 mg/l. Weeks, et al. reported an average dissolved solids content of 1750 mg/l over a much broader range of values, 470 to 6720 mg/l. They also reported "very high" concentrations of fluoride (greater than 9.8 mg/l) and hydrogen sulfide gas in

Table 3-49

MAJOR CONSTITUENTS - ALLUVIAL WELLS

Well	Na	K	Mg	Ca	CO_3	HCO_3	SO_4	Cl
A-1	238	1.7	86	62	8.6	614	448	14
A-2	167	0.8	73	46	7.5	556	254	6
A-3	136	1.2	83	82	4.2	533	358	8
A-5	181	2.0	75	66	8.0	558	337	10
A-6	189	2.0	84	63	6.4	641	343	15
A-7	161	1.0	54	62	5.8	447	299	22
A-8	152	1.9	81	79	7.5	514	390	5
A-9	115	1.1	71	63	6.0	449	307	5
A-10	140	1.6	88	68	2.0	465	419	9
A-11	149	1.9	99	69	4.0	490	457	6
A-12	144	1.8	98	84	4.3	553	472	6



DISTRIBUTION OF MAJOR IONS IN ALLUVIAL WELLS

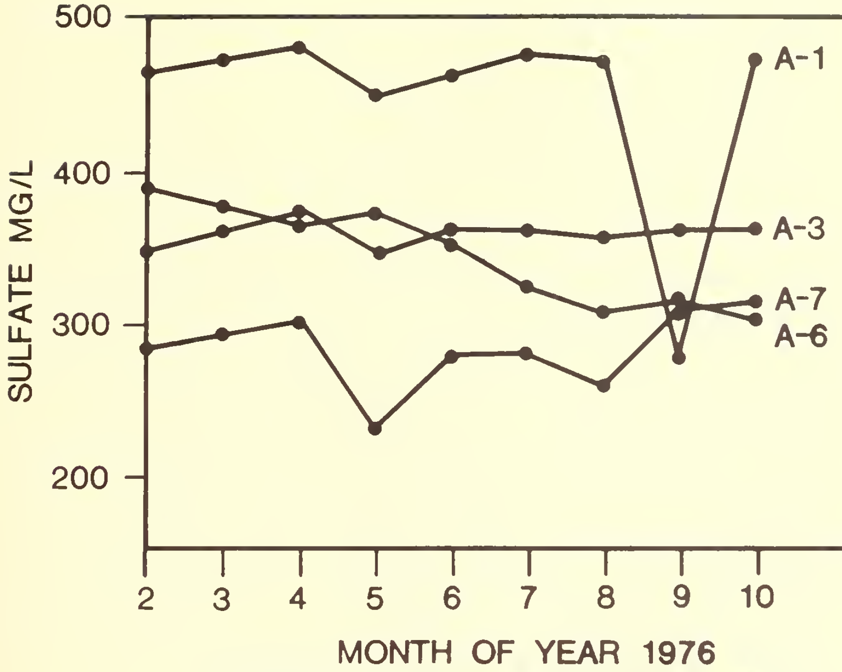
FIGURE 3-53

wells located near faults. They felt that those substances implied communication with the lower aquifer. The water samples from C-b alluvial wells were not sampled for hydrogen sulfide gas, but the typical rotten-egg smell attributable to hydrogen sulfide has not been reported. The maximum concentration of fluoride reported in the C-b alluvial wells was 5 mg/l which would be an excessive concentration for drinking water. However most of the high fluoride readings were reported in the first sampling run which may imply analytical or sampling problems at that time. The first samples were taken by manually bailing the well instead of pumping. The mean fluoride level is only 0.65 mg/l with a standard error of the mean of 0.09.

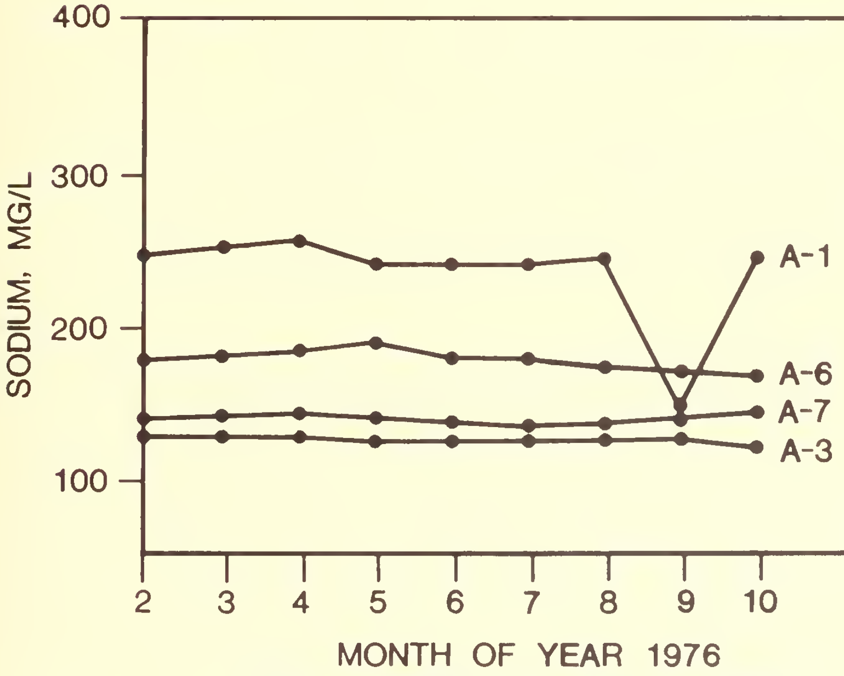
In contrast to the data for springs, no clear correlation with downstream distance can be seen in Figure 3-53. Neither total solids nor any single constituent shows a consistent relationship with downstream distance. It is obvious that local variations in alluvial properties must be exerting a strong effect.

The four wells selected for sampling at frequent intervals during 1976 are A-1, A-3, A-6, and A-7. Data for sodium and sulfate concentrations are representative and are plotted in Figure 3-54. No cylic pattern corresponding, for example, to that shown by the alluvial water level data appears. Except for an atypical analysis for A-1 in September, each well shows a consistent and characteristic concentration which does not change in any way coordinated with the other wells. The fact that seasonal precipitation cycles affect the amount of water in the alluvium (as evidenced by water levels) but do not change the chemical composition might suggest that alluvial water is derived from precipitation by a rather direct route instead of from connections to a deep aquifer system. However, this apparent lack of effect is likely to be simply a result of sampling from the bottom of the aquifer, which is little affected by surface infiltration.

Alluvial water quality is very similar to that for the springs and contains generally a slightly higher concentration of all constituents. Of the 40 mean values for springs listed in Table 3-14 the mean level in the alluvial samples is equal or higher for 32 of those 40 constituents. Conclusions regarding the meeting of water quality standards would be the same as for springs. The only significant difference involving major constituents is the lower calcium content in the alluvium. The lower calcium along with higher sodium makes an appreciable change in the sodium absorption ratio (SAR). For the springs, the calculated SAR is 2.5 compared to 3.4 for the alluvial water. A high SAR is unfavorable for irrigation water because it implies a hazard of sodium replacing absorbed calcium and magnesium in the soil, and this replacement is damaging to soil structure.



SULFATE LEVELS IN ALLUVIAL WELLS



SODIUM LEVELS IN ALLUVIAL WELLS

SULFATE AND SODIUM LEVELS IN ALLUVIAL WELLS

FIGURE 3-54

A complete summary of mean, maximum, and minimum values is given in Tables 3-50 through 3-53 and compared to the same data for springs and deep wells.

3.2.3.5.2 Drilling Water Quality

During the drilling of all the deep wells, records were maintained of the variation of water conductivity with depth. Some of these data have been plotted on cross-sections to illustrate both the vertical and horizontal variability of water conductivities. Figure 3-55 shows two typical cross-sections. In general, the conductivity of the Uinta formation aquifer is between 1000 and 1800 micromhos (μmhos). The water of the Upper Parachute Creek member aquifer is indicated to be less saline than the Uinta Formation waters. It is usually less than 1200 μmhos and commonly under 1000 μmhos. Below the Mahogany zone the conductivity increases again but in this part of the section it generally remains less than 2000 μmhos. Below the R-4 zone, a 50-foot zone of extremely high conductivity water was encountered which had a total dissolved solids content exceeding 30,000 mg/1. On the average, conductivities of water produced during drilling below the R-4 zone were greater than 4000 μmhos.

Of particular interest is the greater conductivity (therefore greater dissolved solids content) of water above the Four Senators aquitard as compared to that below it. This is illustrated in more detail by the data in Figure 3-56.

3.2.3.5.3 Field Measurements

While swabbing the deep wells to obtain samples for water quality analysis, observations are made of water temperature and conductivity as it comes from the well. The depth to water before and after swabbing, as well as the quantity of water swabbed out are also recorded. These data are listed in Table 3-54 for the fall 1976 sampling run.

The amount of water produced varies widely as functions of the properties of the aquifer being produced, such factors as the length of the well open to the aquifer, the type of perforations or openings between the well and the aquifer, the closeness of fit between the swabbing cups and the casing, the depth to water, the height of water column present, and the speed with which the swab is pulled up. Average round trip time per swab was about six minutes, pulling 40 to 100 gallons per run. In three hours of swabbing on the best producing wells about 3000 gallons of water would be produced. SG-20, which flows by itself under artesian pressure, produced over 4000 gallons in only two hours. The least amount of water removed was only 160 gallons at AT-IC-1 and SG-6-3.

Table 3-50

SUMMARY - WATER QUALITY PARAMETERS

		Conductivity	pH	Total Dissolved Solids	Gross Alpha Radiation	Gross Beta Radiation	Total Organic Carbon	Dissolved Organic Carbon
Alluvial Wells	Mean	1380	8.2	996	5	2	5	6
	Number of Values	77	77	77	53	53	31	22
	Maximum	1930	8.7	1300	18	13	9	11
	Minimum	950	7.3	696	0	0	1	2
	Standard Deviation	220	0.3	158	4	4	3	2
Springs & Seeps	Mean	1300	8.2	925	6	4	3	5
	Number of Values	49	50	47	32	32	16	16
	Maximum	1560	8.5	1130	20	30	6	10
	Minimum	840	7.3	547	0	0	1	2
	Standard Deviation	145	0.27	97	4	6	2	2
Upper Aquifer	Mean	1670	8.6	1100	6	3	3	
	Number of Values	52	53	52	49	49	34	
	Maximum	4200	9.1	3100	21	33	9	
	Minimum	800	8.1	520	0	0	1	
	Standard Deviation	700	0.24	490	5	8	2	
Lower Aquifer	Mean	7240	8.7	6190	28	16	10	23
	Number of Values	49	49	49	43	43	27	21
	Maximum	45,000	9.3	42,000	460	390	40	175
	Minimum	630	8.1	356	0	0	1	2
	Standard Deviation	11,800	0.024	11,600	83	60	11	38

Table 3-51

SUMMARY - MAJOR CONSTITUTENTS IN GROUND WATER, MILLIGRAMS/LITER

		NH_3	HCO_3	Ca	CO_3	Cl	OH	Li	Mg	NO_3	PO_4	K	Na	SiO_2	SO_4
Alluvial Wells	Mean	0.5	540	67	6.2	11	--	--	80	1.6	<.09	1.5	175	17	370
	Number of Values	77	77	77	58	77	31	65	77	77	77	66	77	77	77
	Maximum	15	730	102	23	29	1.7	<.5	120	9.1	1.1	5	730	41	530
	Minimum	<.01	320	16	1	0.9	<.1	--	20	<.02	<.01	0.7	93	11	200
	Standard Deviation	1.8	90	21	5	7	--	--	18	2.0	0.1	0.6	86	4	83
Springs & Seeps	Mean	0.12	480	83	2.9	7.1		--	78	2.2	<.05	1.4	130	16	360
	Number of Values	41	50	50	40	50		45	50	45	45	40	50	50	50
	Maximum	0.4	650	160	7.2	18		<.5	100	8.1	0.1	2.3	240	21	440
	Minimum	0.01	320	28	<.1	0.9		--	28	<.02	<.01	0.6	68	12	200
	Standard Deviation	0.1	77	24	3.3	3.9		--	18	2.5	0.04	0.5	28	3	66
Upper Aquifer	Mean	1.2	790	32	21	26	--	--	42	0.41	<.09	2.2	330	17	220
	Number of Values	51	53	53	51	53	33	52	53	52	51	52	53	53	53
	Maximum	7.9	2100	120	76	510	<.1	3.1	150	2.9	0.4	11	1200	32	520
	Minimum	0.1	340	3	<1	2	--	--	2.2	<.02	<.01	0.3	44	4	4
	Standard Deviation	1.3	525	28	18	70	--	--	40	0.57	0.06	2.2	248	6	170
Lower Aquifer	Mean	17	4000	14	220	1200	--	10	11	0.46	<.09	21	2500	13	63
	Number of Values	48	49	49	47	49	27	47	49	49	49	48	49	49	49
	Maximum	200	25,000	220	2000	9800	<.1	79	110	3.4	0.7	120	17,000	38	350
	Minimum	0.1	100	2	7	1	--	1.3	1.5	<.02	0.01	1	140	2	2
	Standard Deviation	42	6,700	34	490	2700	--	23	21	0.77	0.10	36	4700	7	92

Table 3-52

SUMMARY - IMPORTANT TRACE ELEMENTS IN GROUND WATER, MILLIGRAMS/LITER

		Al	As	Ba	Be	B	Cd	Cr	Co	Cu	F	Fe	Pb	Mn	Hg	Ni	Se	V	Zn
Alluvial Wells	Mean	0.3	0.006	0.07	--	0.5	--	--	0.008	0.04	0.65	<.3	0.02	0.2	0.003	0.02	0.009	0.01	0.2
	Number of Values	47	70	50	8	50	5	49	41	50	77	77	50	77	41	48	21	50	50
	Maximum	3	0.05	0.6	<.002	5	<.03	<.1	0.05	0.2	5	9	0.2	2.3	0.048	0.1	0.03	0.2	2
	Minimum	0.01	<.001	0.01	ND	0.001	ND	0.002	<.001	0.005	0.1	<.05	<.002	0.003	0.00002	0.003	ND	<.001	0.01
	Standard Deviation	0.6	0.01	0.1	--	0.8	--	--	0.01	0.04	0.87	0.5	0.03	0.5	0.01	0.02	0.01	0.03	0.4
Springs & Seeps	Mean	0.4	0.005	0.04	--	0.4	--	--	0.007	0.04	0.45	<.4	0.02	0.03	0.0004	0.02	--	0.005	0.08
	Number of Values	33	45	34	5	37	5	34	30	34	50	49	35	33	40	33	14	34	34
	Maximum	3	<.05	0.1	0.002	1.6	<.008	0.1	0.05	0.2	2.1	7.8	0.05	0.2	0.002	0.08	<.04	0.02	0.4
	Minimum	0.004	0.0005	0.01	ND	0.001	ND	0.005	<.001	0.003	0.1	0.01	0.001	0.002	<.00003	0.003	ND	<.001	0.01
	Standard Deviation	0.6	0.01	0.02	--	0.5	--	--	0.01	0.05	0.40	1.2	0.02	0.04	0.0005	0.02	--	0.004	0.08
Upper Aquifer	Mean	0.3	0.01	0.1	--	1.4	--	--	0.003	0.09	10	0.5	0.01	0.1	0.0004	0.02	0.006	0.002	0.2
	Number of Values	48	53	51	14	52	9	50	48	52	53	53	52	53	49	50	33	51	52
	Maximum	4	0.06	0.6	0.003	18	<.02	0.3	0.01	3	190	7	0.07	0.6	0.0031	0.2	0.03	0.006	2
	Minimum	0.003	<.001	0.009	ND	0.01	ND	0.002	<.001	0.003	0.1	<.02	<.002	0.002	<.00003	<.001	<.001	<.001	0.003
	Standard Deviation	0.7	0.01	0.1	--	2.6	--	--	0.003	0.4	26	1.2	0.01	0.1	0.0008	0.03	0.026	0.001	0.4
Lower Aquifer	Mean	0.3	0.02	0.8	--	36	--	<.009	0.006	0.06	21	0.8	0.03	0.1	0.0004	0.01	0.004	0.01	0.2
	Number of Values	45	48	47	18	44	4	47	43	46	49	49	47	48	44	30	23	47	45
	Maximum	2	0.2	8	0.002	400	0.1	0.02	0.03	0.9	48	8	0.4	0.6	0.0027	0.06	0.02	0.1	4
	Minimum	0.002	0.001	0.02	ND	0.05	ND	0.002	<.001	0.003	4	<.05	0.003	0.002	<.00003	<.001	<.001	<.001	0.005
	Standard Deviation	0.4	0.03	1.7	--	100	--	0.004	0.007	0.14	10	1.8	0.06	0.09	0.0007	0.01	0.004	0.02	0.6

Table 3-53

SUMMARY - MINOR TRACE ELEMENTS IN GROUND WATER, MILLIGRAMS/LITER

		U	Th	Cs	I	Sb	Ag	Mo	Zr	Y	Sr	Rb	Br	Ge	Ga	Ti	Sc	W
Alluvial Wells	Mean			0.006	0.007			0.04	0.007	--	1.9	0.01	0.04	--	--	0.3	0.004	
	Number of Values			28	43			41	30	13	76	50	50	6	23	47	50	
	Maximum			0.03	0.03			0.2	0.04	0.007	10	0.06	0.1	0.03	0.03	2	0.02	
	Minimum			ND	0.001			0.005	<.001	ND	0.04	0.002	0.006	ND	ND	0.01	<.001	
	Standard Deviation			0.008	0.007			0.03	0.01	--	1.2	0.01	0.03	--	--	0.4	0.003	
Springs & Seeps	Mean			--	0.005	--	--	0.03	0.005	--	2.0	0.01	0.02	--	--	0.2	0.005	--
	Number of Values			16	26	4	1	27	19	5	49	29	34	3	15	34	34	7
	Maximum			0.02	0.06	0.006	<.001	0.2	0.04	0.003	5	0.05	0.08	0.008	0.006	0.6	0.02	0.02
	Minimum			<.001	<.001	ND	ND	<.005	ND	ND	0.6	0.001	0.004	ND	ND	0.02	<.001	ND
	Standard Deviation			--	0.01	--	--	0.04	0.009	--	1.0	0.01	0.02	--	--	0.2	0.004	--
Upper Aquifer	Mean			0.01	0.006	--	--	0.02	0.006	--	2.4	0.02	0.03	--	--	0.1	0.003	--
	Number of Values	13	4	40	46	11	12	47	28	4	51	50	52	8	33	52	51	8
	Maximum	0.03	<.001	0.2	0.08	0.02	0.05	0.1	0.03	0.01	17	0.05	0.2	0.002	0.004	2	0.009	0.02
	Minimum	ND	ND	<.001	<.001	ND	ND	0.003	<.001	ND	0.1	<.002	0.003	ND	<.001	0.003	<.001	ND
	Standard Deviation	--	--	0.03	0.01	--	--	0.02	0.009	--	2.6	0.01	0.04	--	--	0.3	0.002	--
Lower Aquifer	Mean	--	--	0.2	0.3	--	--	0.04	0.08	--	1.3	0.07	0.7	--	0.007	0.1	0.004	--
	Number of Values	10	1	46	45	24	9	42	36	19	49	47	45	15	37	47	47	13
	Maximum	0.02	<.001	4	3	0.08	0.02	0.2	0.9	0.03	10	0.9	10	0.05	0.06	1	0.01	0.05
	Minimum	ND	ND	<.001	<.001	ND	ND	<.004	<.001	<.001	0.1	0.005	0.003	ND	<.001	0.006	<.001	ND
	Standard Deviation	--	--	0.8	0.7	--	--	0.04	0.2	--	2.1	0.2	2.1	--	0.01	0.2	0.003	--

ND - Not Detected

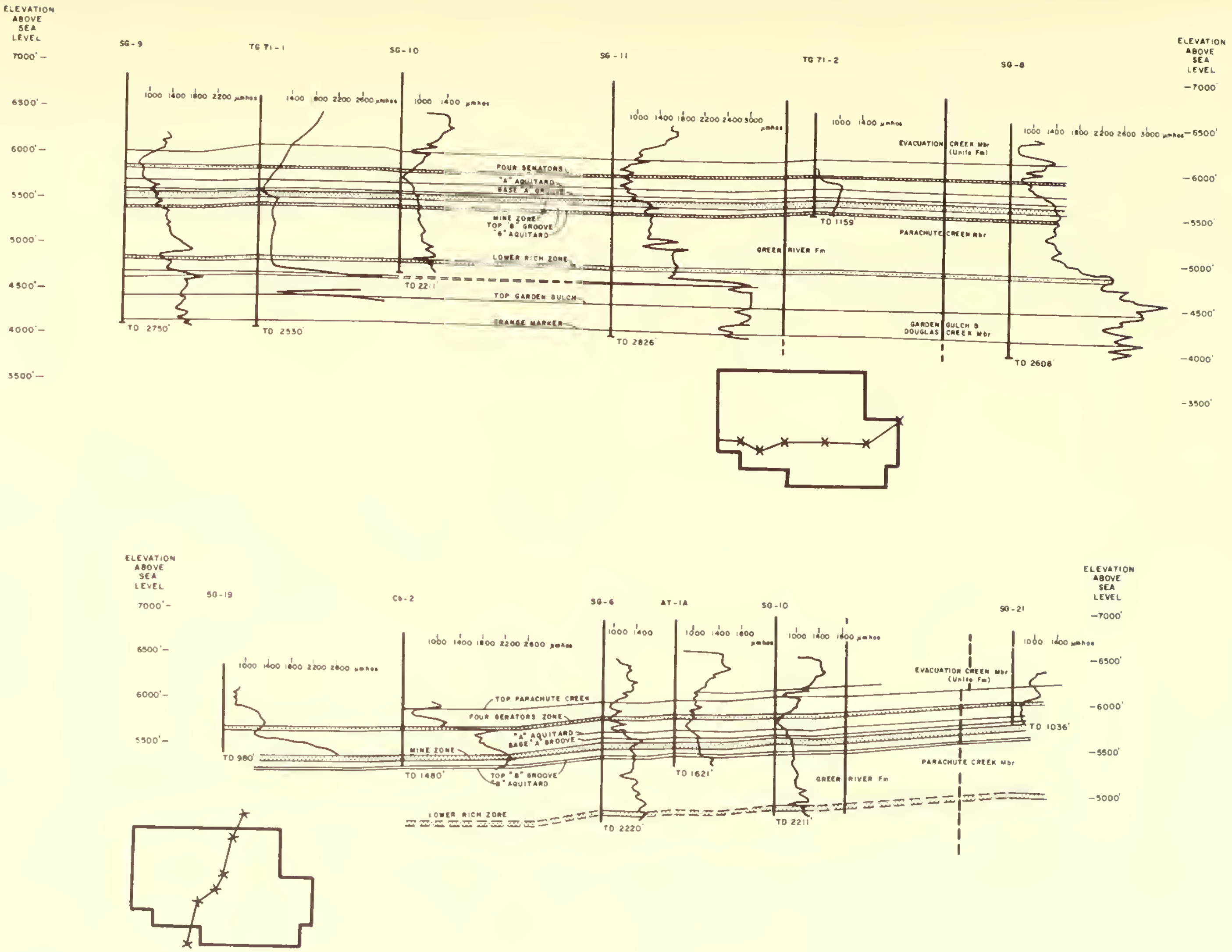


FIGURE 3-55 NORTH-SOUTH AND EAST-WEST STRATIGRAPHIC SECTIONS SHOWING WATER CONDUCTANCE CURVES

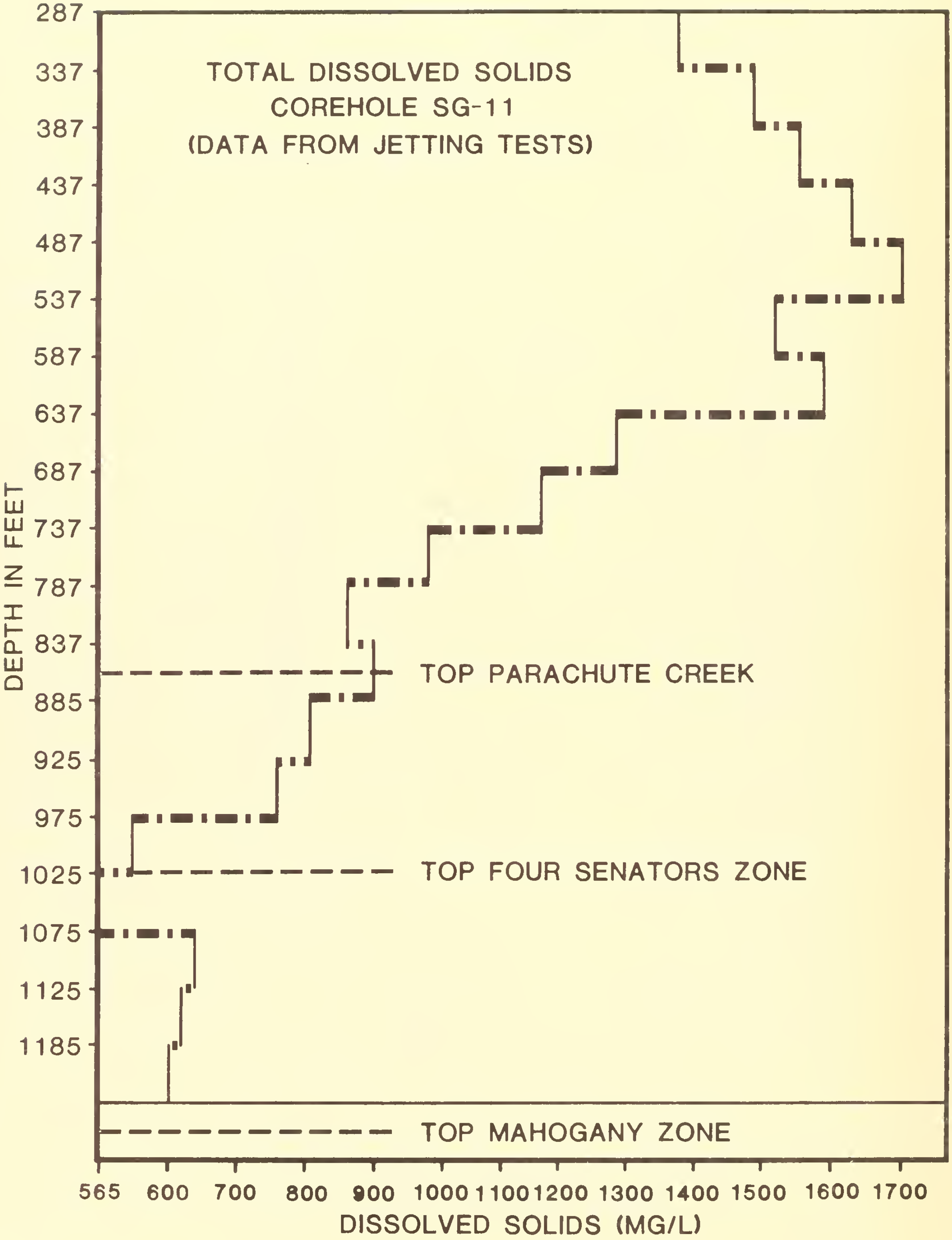

TOTAL DISSOLVED SOLIDS
COREHOLE SG-11
(DATA FROM JETTING TESTS)
DEPTH IN FEET
287
337
387
437
487
537
587
637
687
737
787
837
885
925
975
1025
1075
1125
1185
TOP PARACHUTE CREEK
TOP FOUR SENATORS ZONE
TOP MAHOGANY ZONE
565
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
DISSOLVED SOLIDS (MG/L)

FIGURE 3-56

Table 3-54

FIELD DATA - DEEP WELL SAMPLING

Well String Number	Depth to water at Start	Depth to water at Finish	Conductivity Range	Final Conductivity	^{o}C Temp.	Gallons of water Swabbed	pH
SG-1, #1	69.8	155.1	3000-10,000	8250	17	1260	7.8
SG-1, #2	62.8	65.8	1200-1500	1250	14	2840	7.5
SG-9, #1	362.0	430.6	1300-3400	2000	22	2100	8.0
SG-9, #2	250.8	371.6	1850-2100	1850	15	1150	7.4
SG-21	108.1	109.1	750-1150	1000	16	3210	-
Cb-4	424.6	425.3	800-900	825	15	2300	7.9
SG-11, #1R	405.6	500	14,000-32,000	22,000	19	1220	7.5
SG-11, #2	358.8	500	800-4000	1200	17	530	8.1
SG-11, #3	354.6	500	1600-1800	1790	15	300	7.1
SG-18A	490.1	500	750-1250	1000	18	--	7.7
Cb-2	329.6	242.2	1600-1650	1600	14	2920	7.8
SG-6, #1	394.3	790.0	1800-3100	3000	16	550	8.0
SG-6, #2	376.5	503.4	1300-1400	1300	16	630	8.1
SG-6, #3	337.2	329.5	1350-1550	1550	16	160	8.7
AT-1c, #1	381.2	383.6	1300-1430	1430	16	160	9.3
AT-1c, #2	382.7	500	1200-1300	1250	18	780	8.7
AT-1c, #3	355.1	362.8	1300-1400	1400	19	1320	7.8
Cb-1	357.0	494.5	2200-3800	3550	19	1390	7.8
SG-10A	371.4	372	1400-1500	1500	14	--	7.9
SG-10R	410.0	500	3500-3800	3800	16	290	6.7
SG-19	8.2	4.1	2000-2400	2300	21	1540	7.8
SG-20	Flowing	Flowing	2000-2600	2000	21	4070	7.9
SG-17, #1R	407.9	418.5	4800-5500	5500	21	2580	7.8
SG-17, #2	400.0	427.5	1150-1450	1250	20	2170	8.2
SG-8R	Flowing	8.7	1900-1950	1900	22	2280	8.0

In most cases enough water was removed to cause a significant lowering of the water level at the completion of swabbing. For SG-6-1, the drop in water level was almost 400 feet. In one or two instances, the water level inexplicably increased. At SG-19 the depth to water at start was 8.2 feet and only 4.1 feet at the end. The explanation is probably involved with the suction created behind the swabbing cup and an appreciable resistance to flow at the casing-aquifer interface. As the water level declines with successive swabbing runs, the amount of water produced per run declines accordingly. Also, as the rubber swabbing cups are worn away by abrasion against the tubing surface, more water slips past contributing to a further drop in production. These cups are normally replaced once or twice on each well. Figure 3-57 illustrates the partial restoration of water production caused by replacing the swab cups.

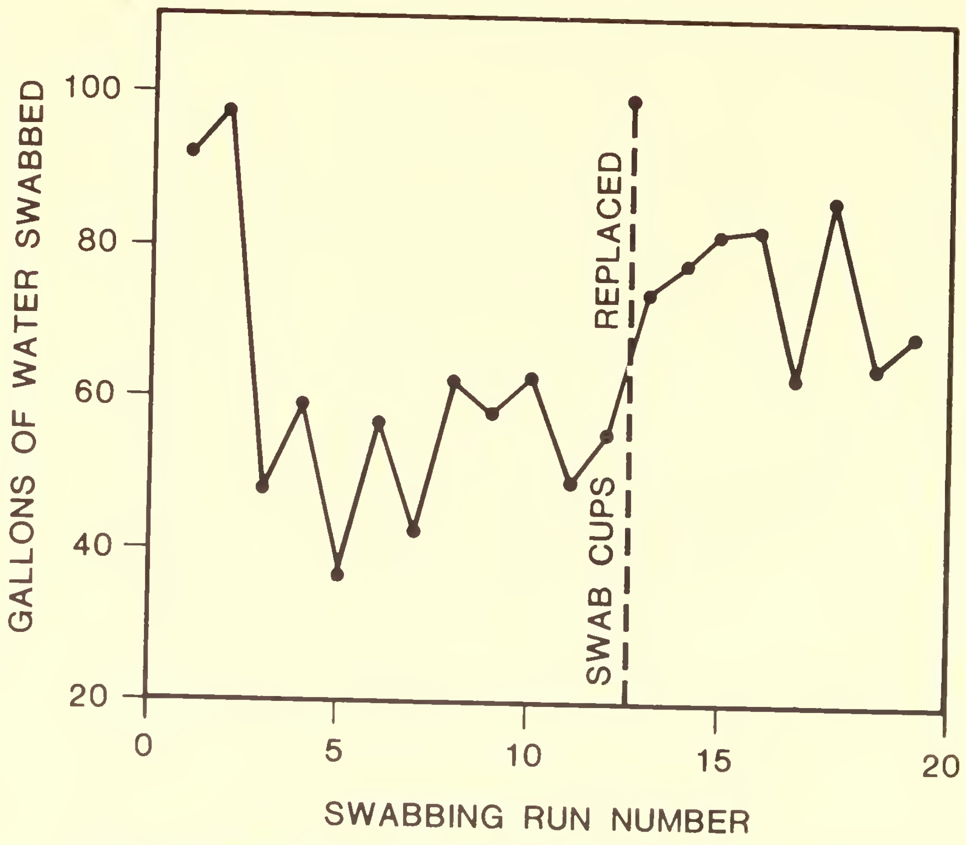
Artesian well SG-20 flowed at a natural rate of 21 gallons per minute before swabbing and showed no change afterward.

Water temperatures ranged from 14^{o} to 22^{o} C. Values for wells which produced only a small amount of water are unreliable because of the time and flow needed to bring the well casing and flowmeter line to equilibrium temperature. Temperature measurements show a normal increase of temperature with depth of water. At well SG-11, water temperature from the deepest string was 19^{o}C, from the middle string was 17^{o}C, and from the shallow string was 15^{o}C. Water from wells SG-19 and SG-20, which both flow as artesian wells occasionally, is anomalously warm.

Conductivity during the first one or two swab runs was sometimes higher and sometimes lower than the final value. Some wells which are perforated over a wide interval produce water with large changes in conductivity during the course of a single swab run. Samples taken from all wells were composited over the length of the last swab run rather than taken at a single point in the run.

3.2.3.5.4 Baseline Data - Deep Wells

A complete listing of all baseline data for the deep wells is given in the appendix in Tables A-17 through A-23 for the upper aquifer and Tables A-25 through A-30 for the lower aquifer. Summaries of maximum, minimum, and mean values were given in Tables 3-50 through 3-53 where they are compared to results from springs and alluvial wells. Many differences in concentrations and occurrences can be noted. In general, the variability of the data is much greater for the deep wells than for the springs and alluvial wells. The variability from well to well is attributed in large part to the highly stratified character of the formations beneath the Tract and the different intervals perforated in each tubing string. Additional well-to-well variability and some sample-to-sample variability for the same well may result from differences in the amount of water



WATER PRODUCTION DURING SWABBING, WELL AT-1C

FIGURE 3-57

swabbed out (removed) during sampling. With a well open to several different strata containing water of different compositions, a composite sample from the well will be most heavily influenced by water from the zones exhibiting the highest production rates. During sampling, each well was swabbed for approximately the same length of time but the amount of water produced was highly variable as was shown in Table 3-54.

Measurable quantities of a wide variety of trace elements are found in the deep wells. In general, iodine, molybdenum, strontium, rubidium, bromine, titanium, and scandium are observed regularly in all samples from the deep wells and also from the springs and alluvial wells. Cesium and zirconium are observed somewhat less regularly in all sources. Uranium, thorium, antimony, silver, yttrium, germanium, and gallium occur fairly often in the deep wells but almost never in alluvial wells or springs. Strontium is the only element of the entire group which regularly appears at levels of 1 ppm or more.

"Important" trace elements are those elements for which recognized Public Health and EPA standards have been written. Given the high dissolved-solids levels in all C-b waters, it might be expected that some of the naturally occurring trace elements would exceed stringent water quality standards. Recently proposed changes to the Colorado Water Quality Standards (Table 3-35) have lower limits for a number of elements than the levels present in C-b aquifers. The most restrictive standards are exceeded by average values in both aquifers for aluminum, ammonia, arsenic, boron, copper, fluoride, iron, manganese, and mercury. In addition, the lower aquifer exhibits excessive levels of chloride and alpha radiation. Maximum values have been recorded in excess of the standards for cadmium, chromium, lead, nickel, selenium, silver, and zinc. Of the constituents listed as exceeding the water quality standards, most are present in only a slight excess, up to a factor of 2 or 3 times the allowable level (Table 3-55). Allowable fluoride levels, however, are exceeded almost universally by an order of magnitude, and very high boron levels are sometimes observed. These two elements exhibit the greatest non-conformity with water quality standards in the deep aquifers. Allowable iron and manganese concentrations are exceeded often but by widely varying margins which are seldom consistent. This indicates that analytical or sampling methods may be at fault for these two elements.

Values for chemical parameters in the lower aquifer exhibit a wide variance because of the extremely high levels of dissolved solids found in some wells penetrating before the R-4 zone. For this reason, average values of parameters in the lower aquifer are not particularly meaningful. If only those wells terminating above the R-4 zone are considered, then the water just below the Mahogany zone does not seem to be greatly different from that just above.

Table 3-55

CONCENTRATIONS IN DEEP WELLS WHICH EXCEED WATER QUALITY STANDARDS (COLORADO)

Constituent	Most Restrictive Standard	Mean, Lower Aquifer	Maximum, Lower Aquifer	Mean, Upper Aquifer	Maximum, Upper Aquifer
Aluminum	0.1	0.3	2.0	0.3	4.0
Ammonia	0.5	17	200	1.2	7.9
Arsenic	0.01	0.02	0.2	0.01	0.06
Boron	0.75	36	400	1.4	18
Cadmium	0.01	--	0.1	--	0.02
Chloride	250	1200	9800	26	53
Chromium	0.05	--	0.02	--	0.3
Copper	0.04	0.06	0.9	0.09	3.0
Fluoride	1.4	21	48	10	190
Iron	0.3	0.8	8.0	0.5	7.0
Lead	0.05	0.03	0.4	0.01	0.07
Manganese	0.05	0.1	0.6	0.1	0.6
Mercury	0.00005	0.0004	0.0027	0.0004	0.0031
Nickel	0.1	0.01	0.06	0.02	0.2
Radiation, Alpha	15	28	460	6	21
Selenium	0.01	0.004	0.02	0.006	0.03
Silver	0.00025	--	0.02	--	0.05
Zinc	0.6	0.2	4.0	0.2	2.0

Data from the upper aquifer monitoring wells confirm the water quality gradient pointed out in Figures 3-55 and 3-56. Namely, that the water just above the Mahogany zone contains less dissolved solids than that nearer the surface. Upper aquifer wells were divided into two groups: those which are open only to a small section of the formation just above the Mahogany zone and those which are open to a more extensive or higher-placed interval. Average analyses for the major constituents plus fluorine are presented in Table 3-56. The difference between the two groups is quite pronounced. It would appear from these data that the aquitards in and near the Four Senators zone may be just as significant a barrier to vertical mixing as the Mahogany zone itself.

It is presumed that TDS concentrations in water increase with time spent underground. In light of the statement that the potential for flow is vertically downward throughout the Tract, it may be difficult to understand how water nearer the surface could have a higher TDS level. This must be explained by imposing a horizontal flow pattern over the entire area. More rapid flow through the horizontal aquifers of greater permeability will result in a shorter residence time and lower solids content at a given point than in the aquifers of lesser horizontal permeability.

The greater solids content in the upper waters is mostly sodium bicarbonate. Sulfate concentration is almost identical. Higher bicarbonate contents in this range of concentration must be obtained by the direct solution of carbonate minerals, rather than from CO_2-derived bicarbonate ions in infiltrating precipitation. The organic activity in C-b soils is not great enough to generate large amounts of CO_2. An interesting hypothesis can be constructed based on the release of CO_2 from the organic material in the rich oil shales, but seems unlikely. The higher fluoride levels in the upper water are also significant. Fluorine is usually tightly bound in minerals and high fluoride waters are rare. Increased fluoride levels are another indication of longer residence times owing to slower flow in the horizontal direction.

3.2.3.5.5 Effect of Well Recompletions

During drilling and testing of the deep core holes, a thin (50 feet) zone of extremely saline water (greater than 30,000 mg/l) was encountered at approximate elevation datum of 4940 feet (2100 feet below the surface at SG-17). This zone appeared to have a higher hydrostatic head than the overlying aquifers. It was apparent after the first year of the baseline program that this poor quality water was moving up the well bore in some of the strings open to that section and mingling with the better quality water above. In the fall of 1975, remedial action was taken to seal off this zone in the wells affected.

Table 3-56

VARIATION IN WATER QUALITY ABOVE THE MAHOGANY ZONE

Wells Sampling only the interval from the Mahogany Zone to 150 feet above	TDS	Na	SO_4	HCO_3	F
Cb-2	1001	367	319	527	2.4
Cb-4	542	140	138	358	0.7
SG-1, St. 2	841	213	228	550	3.1
SG-10A	895	185	383	399	0.4
SG-18A	569	147	105	440	4.0
SG-21	581	184	58	462	9.0
Mean	738	206	205	456	3.3
Standard error of mean	74	31	48	27	1.2

Wells Sampling from more than 150 feet above the Mahogany Zone	TDS	Na	SO_4	HCO_3	F
AT-1c, St. 3	888	218	328	450	4.4
SG-6, St. 3	1110	180	471	437	0.6
SG-8, St. 2	1250	470	75	1200	14.0
SG-9, St. 2	1342	219	486	734	1.2
SG-11, St. 3	1221	369	184	977	5.9
SG-17, St. 2	1472	467	61	1119	15.4
SG-19	1785	802	9	1795	18.0
SG-20	1765	755	10	1812	22.4
Mean	1354	435	203	1065	10.2
Standard error of mean	103	79	66	177	2.7

Three wells, SG-10, SG-11 String 1, and SG-17, String 1 were recompleted. The bottom slotted section in the 2-3/8 inch tubing in SG-10 was sealed off with cement and the well plugged back to 1463 feet. The lower perforations in String 1 SG-17 were sealed off with cast iron bridge plugs set at 1950 feet and 1903 feet and the tubing was plugged with cement back to 1853 feet. SG-11 was plugged to 1928 feet in String 1 with a bridge plug and 50 feet of cement. SG-8, which had been left as an open hole, was also completed, although there was no evidence of aquifer contamination at this point. In SG-8 the tubing and open-hole packer were pulled and the hole was plugged with cement back to 1650 feet. Four and 1/2 inch casing was landed at 1650 feet and cemented from 949 to the surface. The bottom 701 feet of the casing was slotted. After the above re-working, these well strings were designated with an R suffix.

The effectiveness of the re-work program in reducing the TDS levels is illustrated in Table 3-57. The magnitude of decrease in TDS depends upon the rate of mixing in the aquifer. It is expected that the levels will drop even more as the intruded water is gradually dissipated by regional ground water flow in the aquifer.

3.2.3.5.6 Water Quality During Pump Tests

Water samples collected during the aquifer pump tests should provide a better estimate of water quality during sustained yield than that obtained from swabbing samples. Results from the upper aquifer after 23 days of pumping at 350 gallons per minute and from the lower aquifer after 17 hours of pumping at 120 gallons per minute are given in Table 3-58. The level of total dissolved solids in these samples is considerably less than the averages for the respective aquifers obtained from swabbing samples. This confirms the picture of better quality water existing immediately on either side of the Mahogany zone than at either higher or lower stratigraphic elevations. It also suggests that the highest yielding zones have the best quality water. A factor which may contribute to higher concentrations of dissolved solids in the swab samples is the solution of minerals from newly exposed surfaces near the wellbore which were created by the well-drilling process.

If the difference between pump test samples and swab samples is due simply to stratigraphic variations, then continued long-term pumping from near the Mahogany zone might show a gradual increase in dissolved solids as the water in the high-yield interval is depleted and water from the low-yield, lower quality zone provides a larger fraction of the total flow. There is some evidence that this kind of phenomenon may have been occurring during the lower aquifer pump test (Table 3-59). Boron levels appeared to increase significantly during the period of the test. Fluoride levels showed a much smaller increase. This could be due to the fact that boron/fluoride ratio in core samples increases with depth below the Mahogany zone (Figure 3-58).

Table 3-57 EFFECT OF WELL RECOMPLETIONS

Original Well	TDS in water before recompletion	TDS in water after recompletion	New Well Designation
SG-11, String 1	39,000	16,000	SG-11, String 1R
SG-10	42,000	2,800	SG-10R
SG-17, String 1	28,000	4,300	SG-17, String 1R

Table 3-58 WATER QUALITY DURING PUMPING TESTS AT WELL AT-1

Constituent, mg/liter	Upper Aquifer	Lower Aquifer
Bicarbonate	570	755
Boron	1.5	3
Calcium	16	4
Carbonate	-	11
Chloride	7	5
Fluoride	18	19
Magnesium	10	3
Sodium	200	310
Sulfate	4	12
Total Dissolved Solids	560	750

Table 3-59 FLUORIDE AND BORON FROM LOWER AQUIFER PUMP TEST

Date (1975)	Fluoride (ppm)	Boron (ppm)
January 20	18.0	0.65
February 5	18.1	0.88
February 23	20.0	1.15
February 24	20.1	1.10
February 25	20.4	1.13
February 27	18.4	1.2
February 28	20.4	1.6
March 1	20.2	1.42
March 3	19.0	2.58
March 5	20.0	2.02
March 7	21.2	2.18
March 19	23.2	2.00

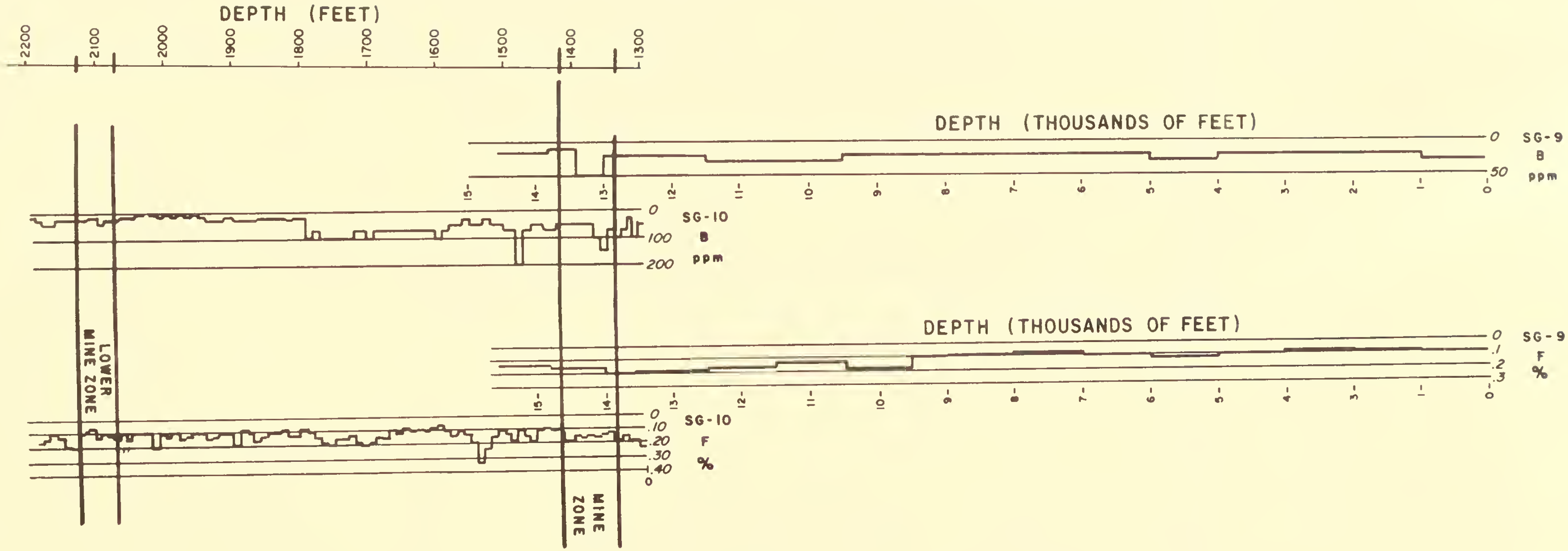


FIGURE 3-58 TRACE ELEMENT STUDY
BORON AND FLUORIDE HISTOGRAMS

3.2.3.5.7 Organic Material in Wells

Water from most of the deep wells on C-b presents a black, slightly oily appearance when swabbed out during sampling runs. A certain amount of the kerogen from the richest oil shale zones is mobile enough to be transported by water into the well-bore. On some occasions, enough viscous, tarry material has accumulated at the water surface in the well tubing to effectively plug the well and prevent a water-level probe from penetrating to the water. Conducting surfaces on the probes often become coated enough to block the flow of electric current and cause equipment malfunctions. The organic material is viscous enough that normal migration rates must be very slow, but the water velocity created by swabbing is enough to displace some material. Well SG-20, for instance, flows clear as a natural artesian well, but turns black when flow is accelerated by swabbing. Some contamination may also result from abrasion of the rubber swabbing cups, and oil and grease from the swabbing cable.

An analysis of material from a water sample obtained at well SG-8 is given in Table 3-60. The composition resembles that of a heavy, waxy crude oil. Solubility of the organic material in water is extremely low. Filtration of water samples in the field removes essentially all of it. A dark brown cake is formed on the filter paper.

Concentration of dissolved organic material in the water is generally less than 20 mg/l (Table 3-50). A special organic fractionation procedure was adopted to study the dissolved material. Samples were collected and separated into a hydrophobic and a hydrophilic fraction. Each of these two fractions was then separated into acidic, basic, and neutral fractions. Several problems arose in the sampling procedure. Some analyses were run on the sample fraction which had been acid-stablized, and some on the filtered-only fraction. During the fall 1976 sampling run, samples were accidentally contaminated with acetone by improper cleaning procedures in the field.

Representative results are summarized in Table 3-61. As might be expected of an analytical procedure still in the developmental stage, especially considering the small concentrations being studied, the data scatter is great. The only clear differentiation between sources is that basic organics occur in significant quantities only in the deep wells. Concentration of basics is no more than 8 percent of the total in any of the samples from alluvial wells, springs, streams, or precipitation, but is higher than this in five of the six samples from deep wells.

Table 3-60 ORGANIC ANALYSIS

Inspections on "As Received" Organic Matter:

Inspection	SG-8	SG-17
Wt % H_2O	20.8	16.6
Wt % Solids	7.4	9.8

Inspections on Dried, Filtered Organic Matter:

Inspection	SG-8	SG-17
API @ 60°F	26.5°	24.6°
S.G. @ 60°	0.8956 g/cc	0.9065 g/cc
Pour Point °F	100°	100°
Viscosity @ 122°F	169 cSt (783.8 SUS)	ND
Viscosity @ 210°F	21.87 cSt (106.3 SUS)	ND
Ash, wt %	0.34%	0.16%
Conradson Carbon Residue, wt %	3.76%	3.75%

ND=not determined

Elemental Analysis of Organic Matter from SG-8:

Carbon, wt %	85.10
Hydrogen, wt %	12.44
Nitrogen, wt %	0.33
Oxygen, wt %	1.05
Sulfur, wt %	1.15
Total	100.07

Table 3-61

ORGANIC FRACTIONATION RESULTS

	Total	PERCENT OF TOTAL DOC					
	DOC,	HYDROPHOBICS			HYDROPHILICS		
SAMPLE SOURCE	ppm	Acids	Neutrals	Bases	Acids	Neutrals	Bases
Well A-1	3.8	49	7	8*	36**	36**	8*
Well A-3	1.8	44	28	0	28*	28*	0
Well A-6	3.5	40	23	6*	31**	31**	6*
Well A-7	2.6	23	35	8*	35**	35**	8*
Stewart Creek	16.1	6	13	0	9	72	0
Willow Creek	3.2	38	3	0	34	12	12
Upper Piceance Creek	4.5	40	9	0	20	20	11
Lower Piceance Creek	5.1	35	18	0	31	10	6
Spring S-3	2.5	32	16	8*	44**	44**	8*
Spring S-9	1.6	56	6	0	38**	38**	0
Snow at C-b-2	2.8	18	11	0	71*	71*	0
Snow at SG-18	2.0	20	5	5*	70**	70**	5*
Well SG-6, String 1	3.8	32	16	29*	24**	24**	29*
Well SG-6, String 2	3.1	26	32	16*	35**	35**	16*
Well SG-6, String 3	1.7	24	0	24*	71**	71**	24*
Well SG-8R	3.5	20	26	9*	46**	46**	9*
Well SG-10R	5.1	45	27	6*	22**	22**	6*
Well SG-20	2.6	54	12	27*	8**	8**	27*

*, ** Indicates combined total for fractions shown.

3.2.3.5.8 Gas in Water

The conditions of approval for the core drilling and associated ground water program specified the collection of gas samples from drill holes penetrating the Mahogany and/or R-4 zones. Evidence of gas evolution may be seen in many of the wells. Gas bubbles or froth often appear in the water produced during swabbing runs. At well SG-20 in particular, gas pressure will build up to over one hundred psi when the well is closed in.

Gas evolved during drilling could be (1) in solution in the ground water, (2) contained in open fractures and joints and trapped there by the ground water, or (3) actually trapped within the pore spaces. Measurements of the gas evolved during drilling and from recovered cores showed large variations with depth.

A gas meter installed on SG-11, String 1 exhibited numerous peaks and valleys with flows ranging from one to six cubic feet per minute over a 21-day period. The cyclic behavior probably results because the hydrostatic head of water retards gas release until the gas pressure builds up enough to break through the water column. Gas is then produced until the driving pressure is again reduced below hydrostatic. This phenomenon is not uncommon in gas-saturated oil wells. It implies a low formation permeability or poor communication between the formation and the well bore.

A gas-water separator was installed in the flow line from well AT-1 during the aquifer pump tests. Gas production as a function of time is shown in Figures 3-59 and 3-60. At the prevailing temperature and pressure in the aquifer, the solubility of methane in water is on the order of four times the quantity of gas observed. Thus only dissolved gas was being produced. Analysis of the gas produced during the upper aquifer pump test gave an average of 49 mole percent methane, 3000 ppm ethane, and the balance air. Data from the lower aquifer test indicated approximately 75 percent methane (Table 3-62). Gas samples collected from various wells flowing gas have ranged from 15 to 80 mole percent methane. Gas/water ratios have been observed from 4 or 5 cubic feet per 1000 gallons to as high as 65/1000 at SG-8.

3.2.4 Correlations - Model Studies

3.2.4.1 Mine Water Inflow

A number of attempts have been made to use digital computer models to estimate the rate at which water would flow into an underground mine on Tract C-b. An early effort was made by Weeks, Leavesley, Welder, Saulnier, in USGS Professional Paper 908. Using a simple model which assumed instantaneous and complete removal of

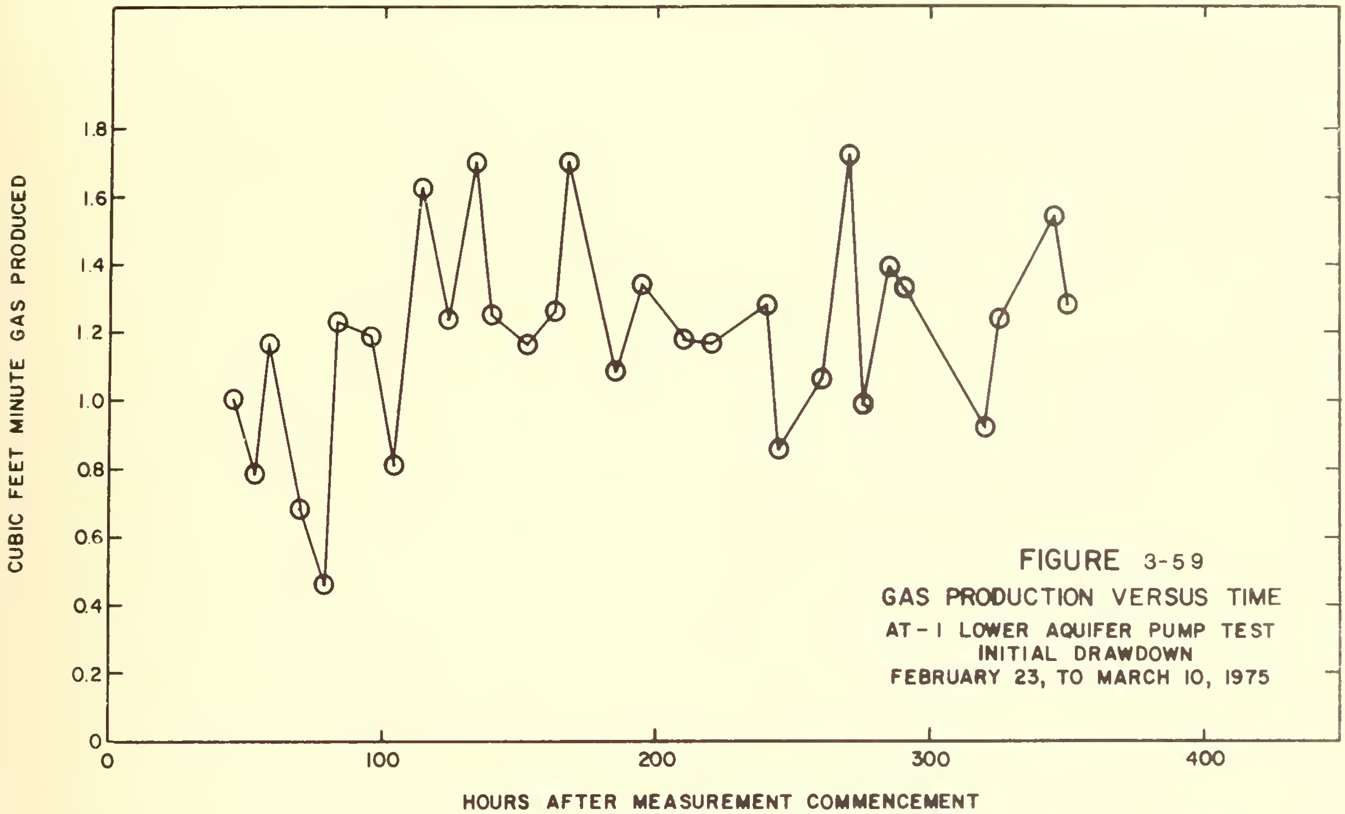


FIGURE 3-59
GAS PRODUCTION VERSUS TIME
AT-1 LOWER AQUIFER PUMP TEST
INITIAL DRAWDOWN
FEBRUARY 23, TO MARCH 10, 1975

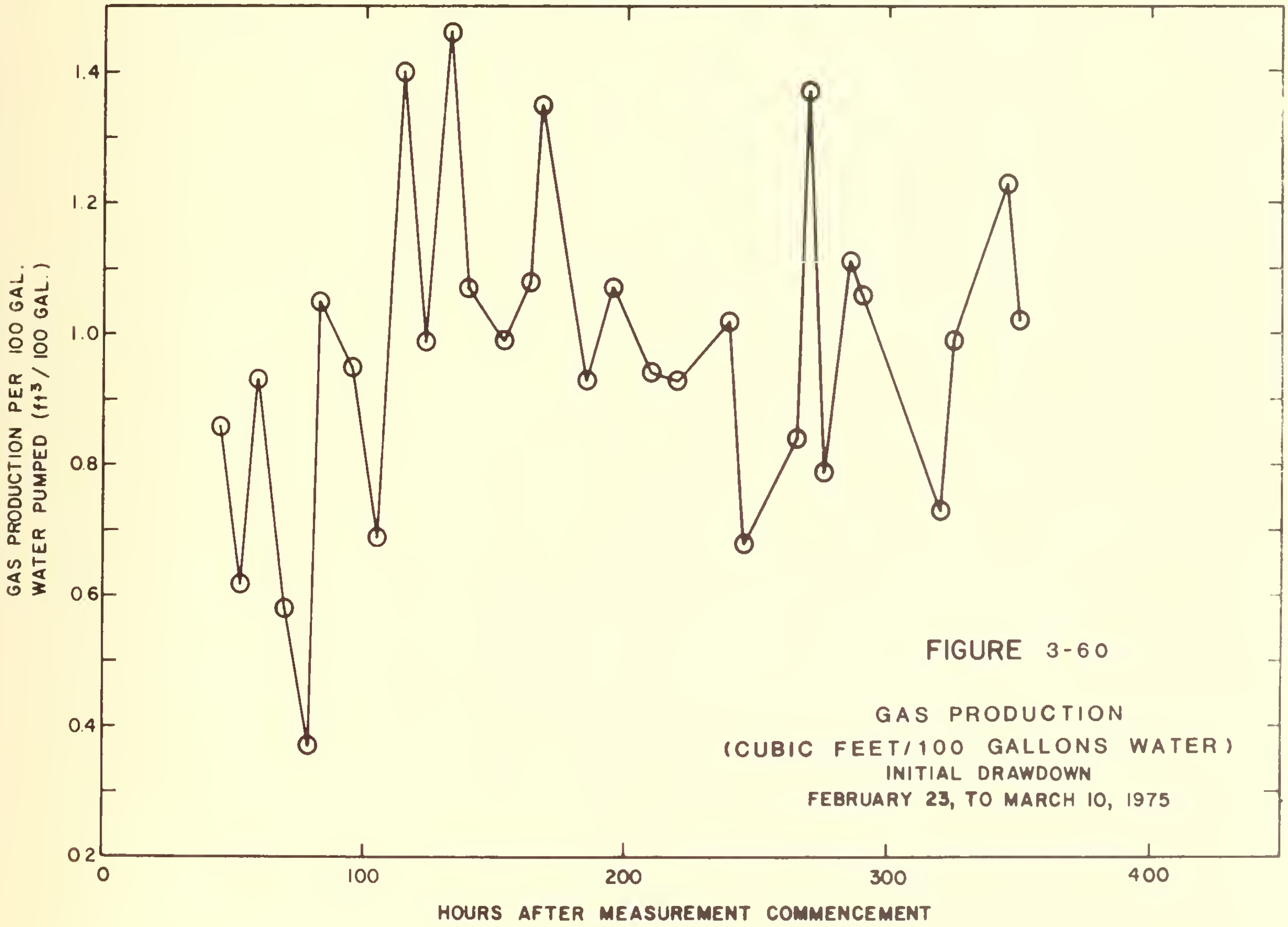


FIGURE 3-60

GAS PRODUCTION
(CUBIC FEET/100 GALLONS WATER)
INITIAL DRAWDOWN
FEBRUARY 23, TO MARCH 10, 1975

Table 3-62

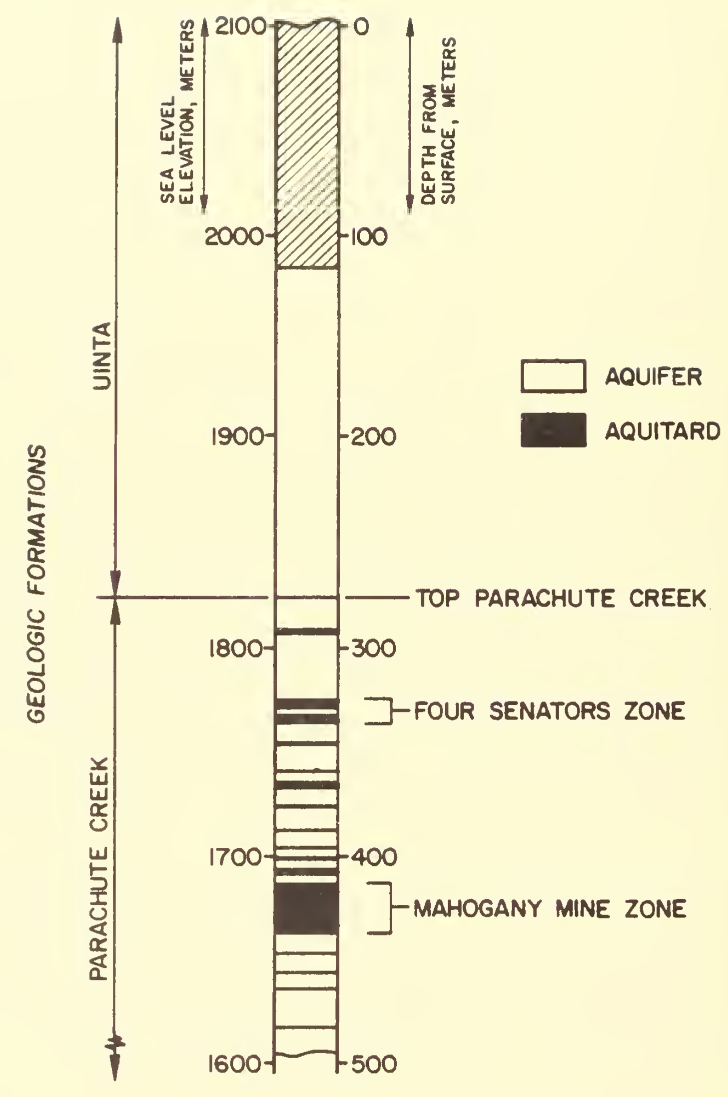
GAS SAMPLE ANALYSIS LOWER AQUIFER TEST

Date and Description	Methane (mole %)	Ethane (Vppm)	Ehylene (mole %)	CO_2 (mole %)	Balance Air
2-16-75	72.12	200	0.39	---	Air
3-6-75 1400 Hr.	77.47	229	---	0.15	Air
Lower Aquifer Drawdown 3-9-75 1500 Hr.	78.43	100	---	0.15	Air
Average Value Initial Drawdown	76.01	176	---	0.15	Air
Lower Aquifer Pulse Test 3-26-75	75.67	311	0.45	0.16	Air
Average All Values	75.92	210	0.42	0.15	Air

the entire Mahogany zone plus all overburden and water contained therein at time zero, they computed mine inflow as a function of time. Their results are obviously meaningless for the early years because of the assumption of instantaneous and complete dewatering, but this assumption will have little effect for the later years. Total flow was indicated to be on the order of 22 cubic feet per second. The model consisted of two aquifers, separated by the Mahogany zone.

Drillstem tests have shown the actual situation under Tract C-b to be as illustrated in Figure 3-61, a complex series of alternating aquifer and aquitard layers. Several attempts have been made to develop a more realistic model, of which only two will be discussed. The "wedding cake" model (Figure 3-62) divided the upper aquifer into a series of zones. This model was used to estimate the inflow into either one or two large (30 ft. diameter) vertical mine shafts (Figure 3-63), into a 40-acre pilot mine (Figure 3-64), or into a full-scale mine. Inflow to a single, unlined mine shaft peaks at about 1400 gpm and then drops off. Any type of shaft lining would greatly reduce this flow -- essentially to zero in some cases. Inflow to a 40-acre mine is no more than that to the shaft alone, because the vertical component of flow is very small. Leakage across the aquitards is negligible compared to horizontal flows into the mine. Flow rate into the full-scale mine is even larger than for the USGS model, mostly because of including the effect of storage in the aquifers above the mine (assumed to have instantaneously vanished in the USGS model). A key assumption built into the model was the existence of fault zones, or zones of increased vertical permeability, along Stewart, Willow, and Piceance Creeks. This allowed vertical flow along the lines of the Creeks. Because of the much greater resistance to flow in the vertical direction, an assumption of free vertical communication at any point on or near the Tract will have a very strong effect on computed mine flows. There is no direct quantitative evidence for such aquifer communication.

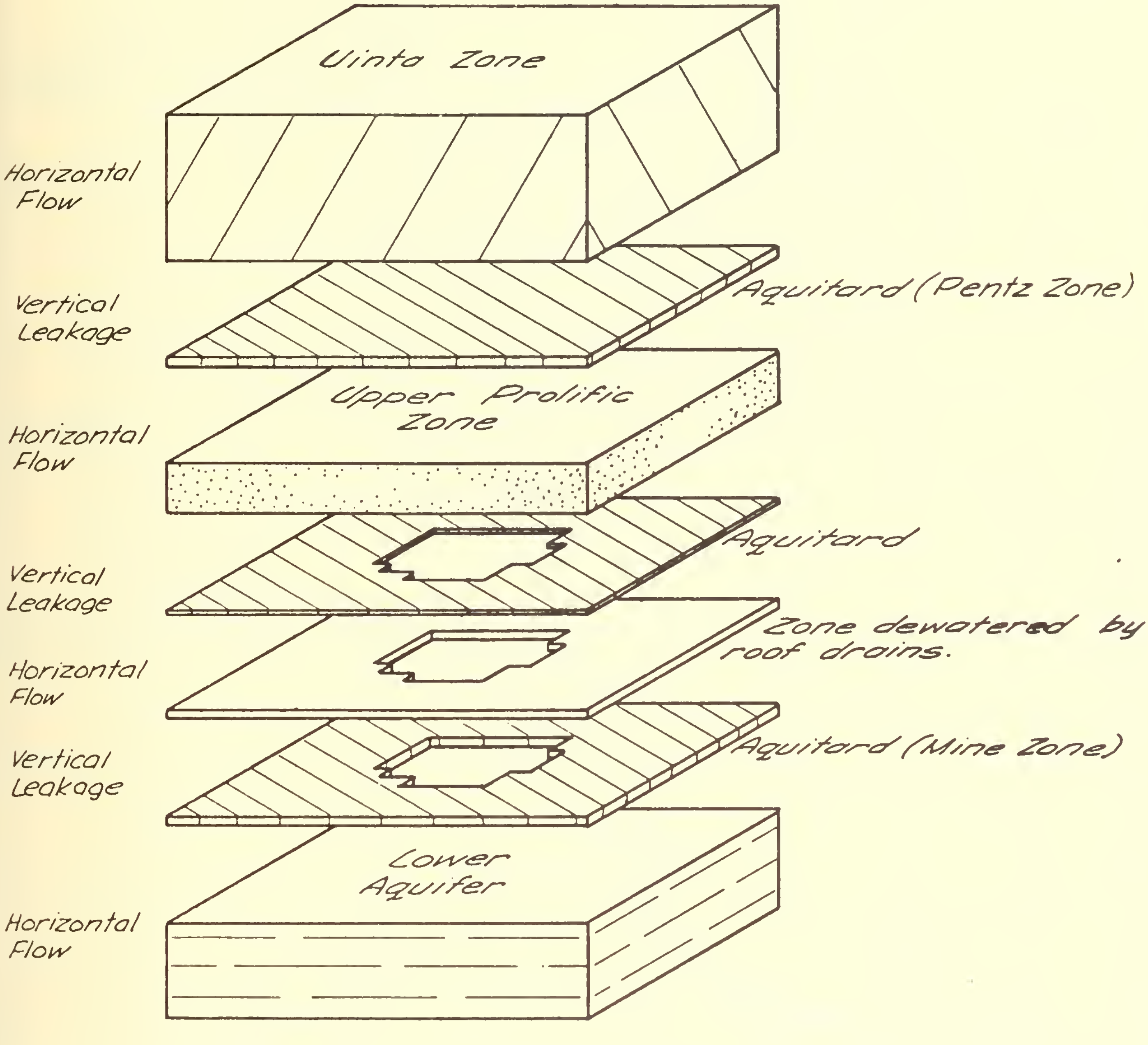
A more extensive 3-dimensional computer model was set up with a total of eight different horizontal zones having properties as shown in Figure 3-65. Vertical hydraulic conductivities shown are best estimates for the data generated on Tract C-b. Horizontal anisotropy is assumed as observed during the aquifer pump tests. Porosity is assigned based on barometric efficiency. Areal homogeneity of aquifer properties is assumed. Results calculated with this model were felt to be the best estimate possible using only the measured aquifer characteristics. The maximum flow rate was found to be less than 7000 gpm. The range of various estimates is illustrated in Figure 3-66. More recent estimates have indicated lower flow rates.



SECTION SHOWING AQUIFERS AND AQUITARDS

FIGURE 3-61

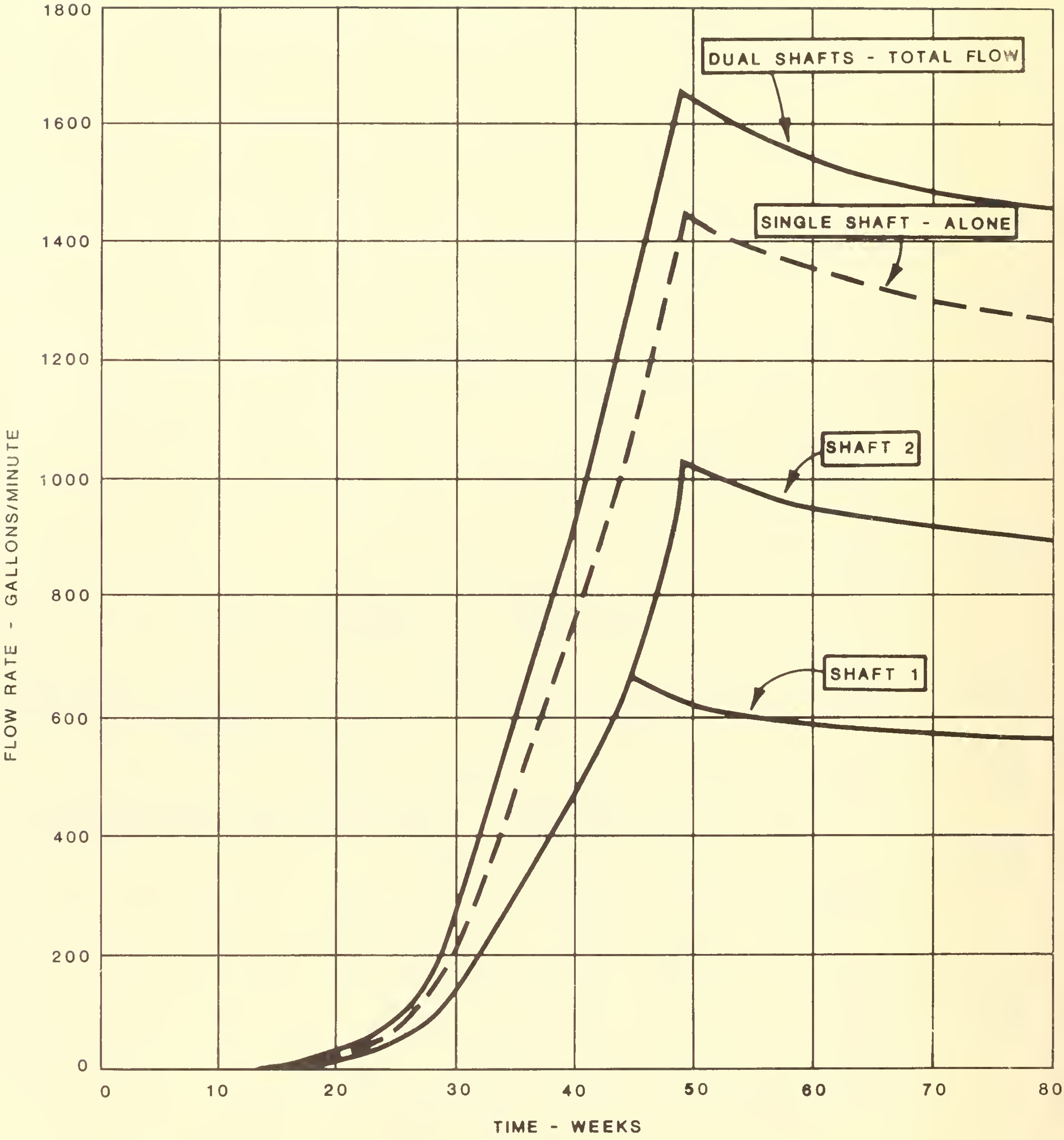
WEDDING CAKE MODEL SKETCH



Not to Scale

NOTE:
All resistance to vertical flow is concentrated in the Aquitards.

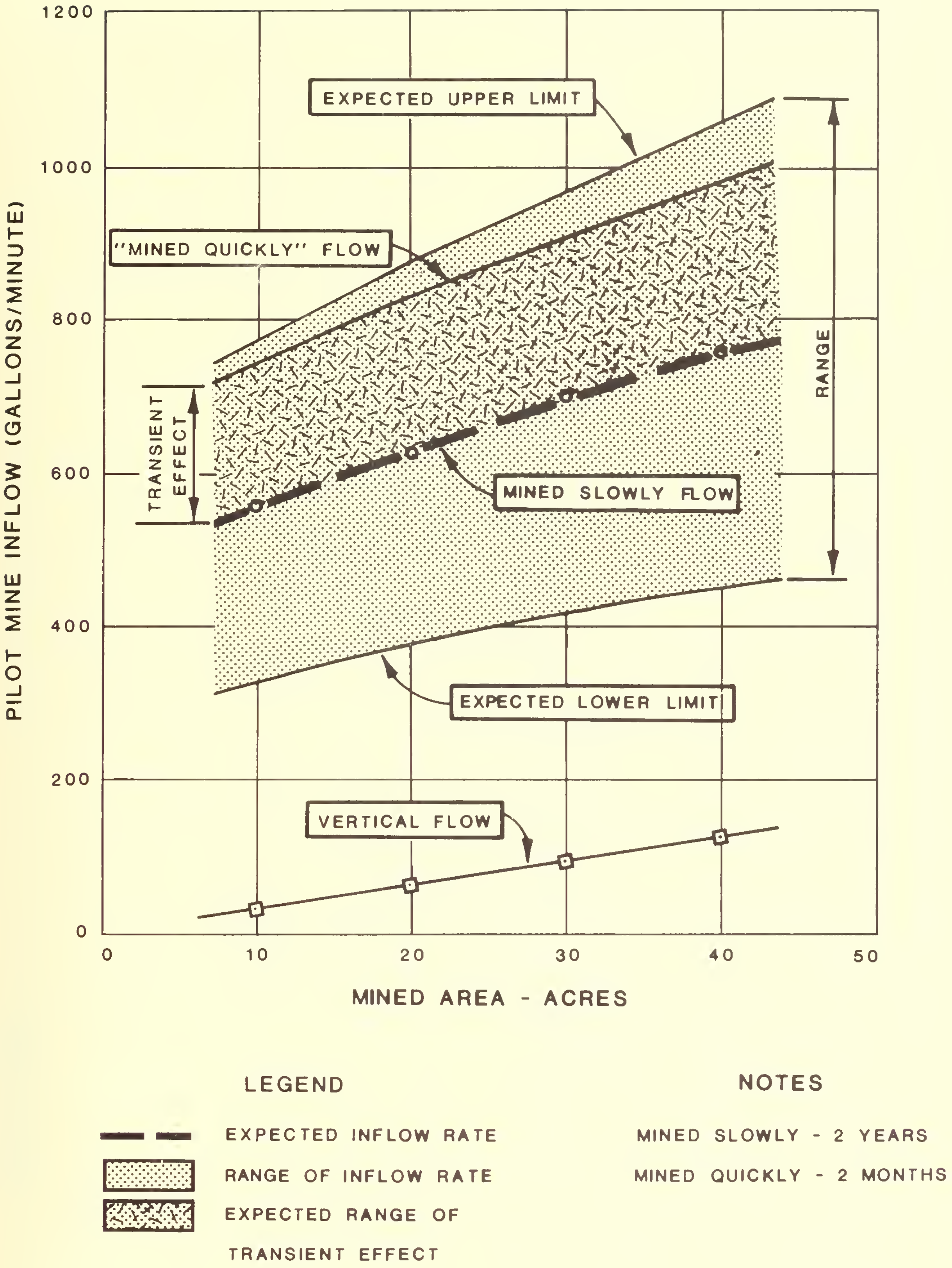
FIGURE 3-62



NOTE: FLOW IS FOR UNLINED SHAFTS.

SHAFT INFLOW vs TIME

FIGURE 3-63



PILOT MINE INFLOW ANALYSIS RESULT

FIGURE 3-64

HYDROGEOLOGIC CHARACTERISTICS FOR COMPUTER MODEL

THICKNESS (FEET)	STRATIGRAPHIC DIVISION	HYDROLOGIC ZONE	HYDROLOGIC CLASSIFICATION	HORIZONTAL PERMEABILITY MD		VERTICAL PERMEABILITY MD	POROSITY	LAYER NO.
				MAX.	MIN.			
	GROUND SURFACE							
VARIES	UINTA		WATER TABLE					
535	FORMATION	UINTA ZONE	UPPER AQUIFER	33	3.3	3.3	0.2	1
180	PARACHUTE	PENTZ ZONE		165	16.5	16.5	0.15	2
33		4 SENATORS ZONE		128	12.8	0.44	0.15	3
137		UPPER PROLIFIC ZONE		112	11.2	2.65	0.15	4
120				134	13.4	0.83	0.15	5
75	MAHOGANY	MINING ZONE	MAHOGANY ZONE	25	2.5	0.002	0.05	6
335	CREEK	LOWER PROLIFIC ZONE	LOWER AQUIFER	31	3.1	2.1	0.15	7
450		LEACHED ZONE		50	5.0	5.0	0.15	8
	LOWER RICH ZONE							

FIGURE 3-65

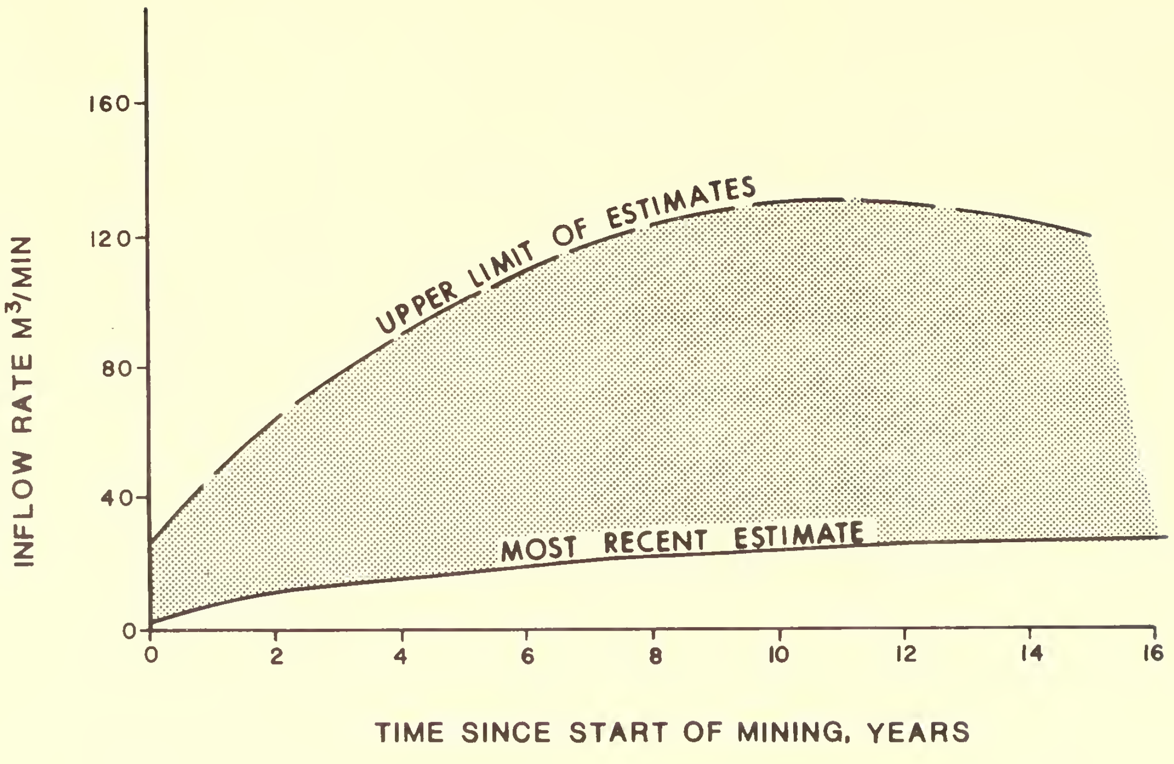


FIGURE 3-66 MINE INFLOW RATE

3.2.4.2 Reinjection of Mine Water

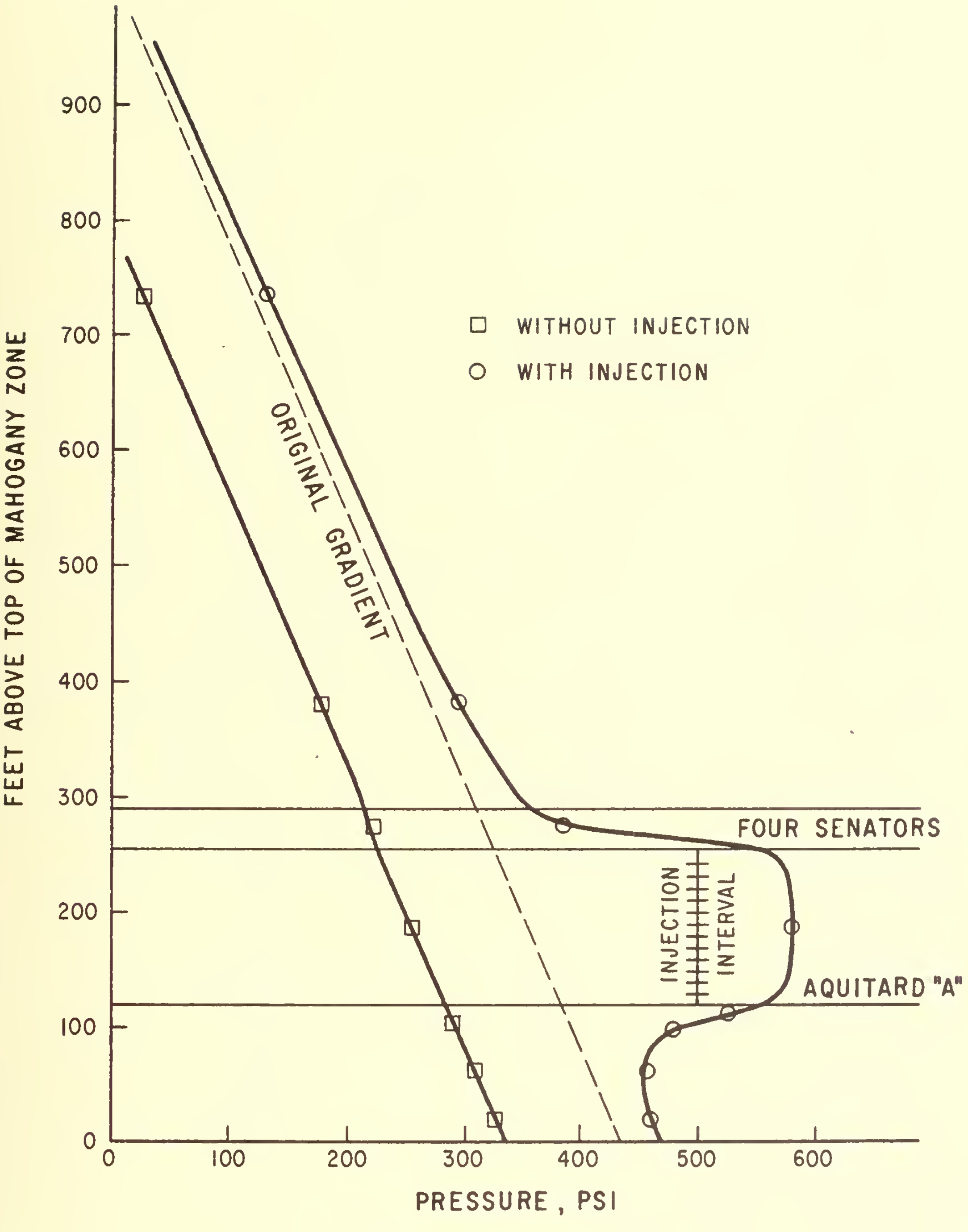
A logical procedure for handling any excess mine water encountered at any stage of operations is simply to reinject the water back into the aquifers from which it came. Since approximately 80 percent of the water would come from the upper aquifer, this would be the obvious choice for reinjection. A simulation run was made for the pilot mine case with reinjection of all inflow water. During this stage of development there is likely to be no large water requirement and therefore all water would be reinjected. The reinjection interval chosen is a 150-ft. section just below the Four Senators aquitard (Figure 3-67). Three injection wells were assumed, spaced one mile apart on an east-west line located one mile north of the mine site. Figure 3-67 is a pressure profile at injection well number 1 after 2800 days, showing the original gradient, the result if water is reinjected and that if it is not reinjected. Pressures within the injection interval between the two aquitards are increased by 150 to 250 psi, but outside this interval the effect is quite small. The increase in pressure will cause some increase in flow into the mine - from 840 to 980 gpm.

A plot of water pressure at an elevation above the mine roof vs distance, on a cross-section through the pilot mine, is shown in Figure 3-68. Above the mine itself, all water is drained and the pressure is zero. On the injection well side of the mine, pressures are higher than before development at distances of more than 4000 ft. On the opposite side of the mine, pressures are decreased, but only about half as much as when no water is reinjected. In terms of flow in the overall ground water system, the net effect should be zero. Water is simply flowing into the mine and then back into the system via the injection wells. Since the pressure profiles have been altered, however, some springs and seeps (near the injection wells) may experience an increase in flow, while others will show a decrease.

A similar reinjection study was run for a fully developed mine. Ten injection wells were assumed. In this case, only water in excess of that required for processing is reinjected. Figure 3-69 shows the water level distribution along the line of reinjection wells after 20 years of operation. Increases of up to 150 feet in water level were indicated. It is emphasized that although water levels are increased along the line of injection wells, the overall ground water supply has been reduced by the amount of water (approximately 5000 gpm) consumed in processing.

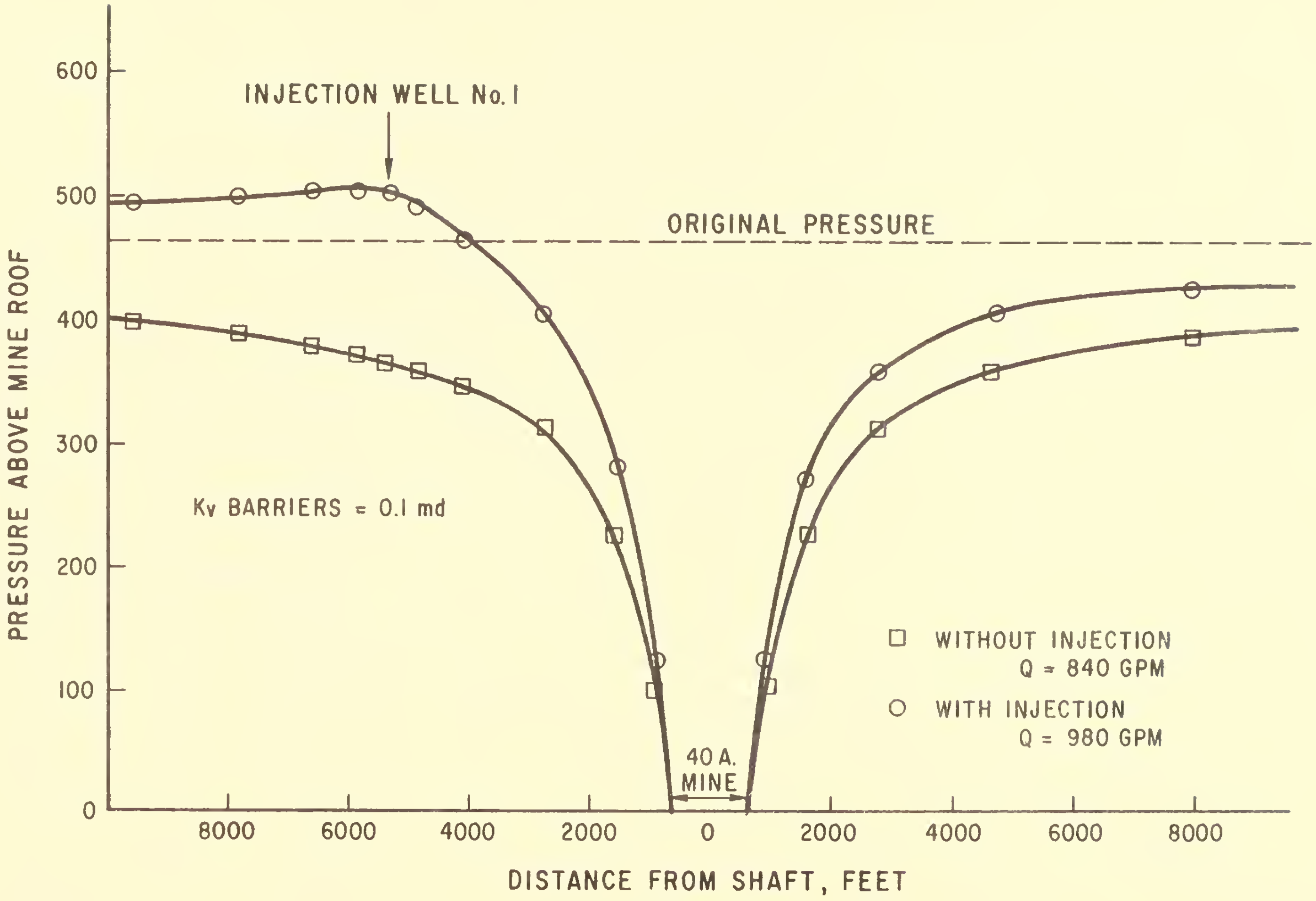
3.2.4.3 Statistical Variance of Hydrologic Parameters

In a homogeneous aquifer system, one would expect mean values for water quality parameters to be invariable. On the other hand, water quality data obtained in a highly non-homogeneous system such



PRESSURE AT INJECTION WELL NO. 1

FIGURE 3-67



PRESSURES AT 2800 DAYS

FIGURE 3-68

WATER LEVEL DISTRIBUTION ALONG TRANSECT OF INJECTION WELLS AFTER 20 YEARS

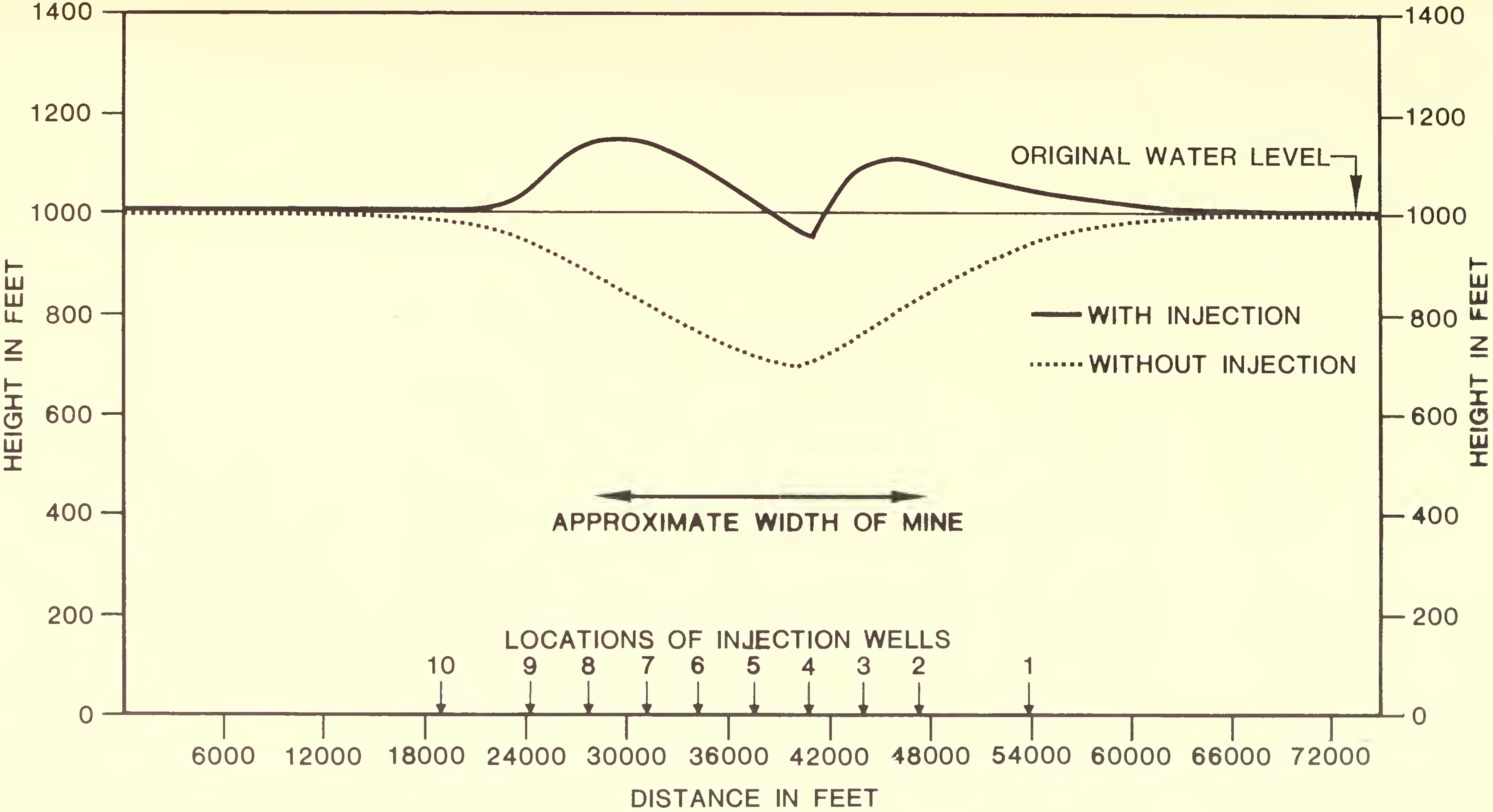


FIGURE 3-69

as that under Tract C-b can be used to examine interrelationships between various parts of the system. If any two or more parts of the aquifer system are in free hydraulic communication, then mixing should occur and the water quality parameters should blend together. Using this hypothesis, the ground water data were used to test for the existence of hydraulic continuity between the four major hydrologic units: 1) upper aquifer, 2) lower aquifer, 3) alluvial aquifer, 4) springs.

The vertical hydraulic conductivity of the Mahogany zone is low enough to place it in the classification of impermeable aquifer. For all practical purposes it obstructs communication between the upper and lower aquifer. However, under a large differential pressure, the flow through even an almost impervious layer could be substantial when summed over a large area. The major purpose of this exercise was to shed light on the question of interconnections between the springs and the various aquifer systems.

A statistical test was conducted utilizing the mean values of the water quality parameters from samples collected over the first year and one half of the baseline program. The test was based on the asymptotic distribution of likelihood ratio for samples from more than two populations. The test was applied to the equality of 29 parameters for all eleven possible combinations of four hydrologic units (taking four units, three units, and two units at a time). A test of size $\alpha = 0.05$ (probability of rejecting the true hypothesis that the samples are derived from the same population) was selected.

Table 3-63 gives the results of the statistical inference concerning the identity of the four hydrologic units. Twenty-two of the 29 parameters suggested no intercommunication and no mixing. An "x" in the table indicates that the statistical analysis of the means and variances for that water quality parameter showed that the means could have come from the same population (i.e., water is from the same mixed source) and an "o" indicates a 95 percent probability that they did not. The predominant results suggest no intercommunication between the aquifers and no source for the springs in any of the 3 aquifers defined. This data cannot be taken as conclusive, but provides support for the concept of a rigidly stratified aquifer system with almost no vertical communication.

Table 3-63
STATISTICAL INFERENCE ON INTERACTION BETWEEN FOUR HYDROLOGIC UNITS

U-upper aquifer: L-lower aquifer: A-alluvial aquifer; S-springs

Combinations Water Quality Parameters	ULAS	ULA	ULS	UAS	LAS	UL	UA	US	LA	LS	AS
Ca	0	0	0	0	0	0	0	0	0	0	0
CO_3	0	0	0	0	0	0	0	0	0	0	0
Cl	0	0	0	0	0	0	0	0	0	0	0
Li	0	0	0	0	0	0	0	0	0	0	0
Mg	0	0	0	0	0	0	0	0	0	0	0
NO_3	0	0	0	0	0	0	0	0	0	0	0
PO_4	X	X	X	X	X	X	X	0	X	X	X
K	0	0	0	0	0	0	0	0	0	0	0
Na	0	0	0	0	0	0	0	0	0	0	0
SiO_2	X	X	X	X	0	X	X	X	X	X	X
SO_4	0	0	0	0	0	0	0	0	0	0	0
NH_3	0	0	0	0	0	0	0	0	0	0	0
Al	X	X	X	X	X	X	X	X	X	0	X
Ba	0	0	0	0	0	0	0	0	0	0	0
B	0	0	0	0	0	0	0	0	0	0	0
Co	0	0	0	0	X	0	0	0	X	X	X
F	0	0	0	0	0	0	0	X	0	0	0
Pb	X	X	X	X	X	X	0	0	X	X	X
Mn	0	0	0	0	0	0	0	0	0	0	0
Mo	X	0	X	X	X	0	0	X	X	X	X
Ti	0	0	X	X	0	0	0	X	0	0	0
Cond.	0	0	0	0	0	0	0	0	0	0	0
pH	0	X	0	X	X	0	X	0	X	0	X
TDS	0	0	0	0	0	0	0	0	0	0	0
Palk	0	0	0	0	0	0	0	0	0	0	0
MOalk	0	0	0	0	0	0	0	0	0	0	0
Hard.	0	0	0	0	0	0	0	0	0	0	0
TOC	0	0	0	0	0	0	0	0	0	0	0
HCO_3	0	0	0	0	0	0	0	0	0	0	0
TOTAL "X"s	5	5	6	7	6	4	4	5	7	5	7

X indicates that the means may be from same population
0 indicates that the means are not from same population

4.1 Uses for Data

Data obtained during the two-year Baseline Environmental Monitoring Program may be utilized as (a) an accumulation of background data which establishes reference levels that will be used with production monitoring data to measure future changes; (b) an aid in designing the monitoring program to be followed during future development and operational phases of the project; and (c) to influence the nature of development plans and procedures. As a specific example of the last item, and also related to the first two, the measurement of universally high fluoride levels in the deep aquifers led to the conclusion that direct discharge of mine inflow waters would be unacceptable. Comparison with the low fluoride levels in the springs led to the hypothesis that the springs were not directly connected to the deep aquifers. This in turn suggested that the mining zone could be dewatered and the water reinjected into the upper aquifer without having a major effect on the spring flows.

The major discussion in this section will be focused on item (b), the design of a suitable on-going environmental monitoring program. If the baseline program had been designed with perfect foresight, then all data collected would meet future needs, no additions or changes to the program would be necessary for monitoring purposes, and no simplifications or reduction of effort would be desirable. In the absence of perfect foresight, it is of value to study the results obtained for the purpose of improving the usefulness of future monitoring efforts.

The baseline program was designed to cover all parameters of possible importance without knowing in advance what the occurrence, concentration, and importance of those parameters might be. For instance, water quality monitoring was instituted on ephemeral streams without knowing what the flows might be. Because no significant flow has been observed on most of those streams during the baseline period, the data collected to date do not justify more extensive water quality monitoring at these sites. On the other hand, the baseline program has revealed certain deficiencies in earlier concepts of the Tract hydrology and a need for additional data in some areas. An example of this is the two-aquifer concept surrounding the mining zone. It was originally assumed that there were essentially two deep aquifers separated by the Mahogany zone. Observation wells were completed in accordance with this concept. It is now known that the geology and hydrology is much more complex and that highly stratified aquifers and aquitards characterize the aquifer system. Changes in configuration of the observation wells should be based on this new and more detailed information.

The data required for a monitoring program and their spatial and temporal resolution depend on the setting and on the kinds of human intervention being considered. Monitoring can be defined as the activity of making systematic observations of parameters related to a specific system with the object of providing information on the characteristics of the system and how these characteristics change with time. Some of the requirements for information from a monitoring network are to: (a) ascertain the current status of water quality required for planned management of water resources, (b) determine the extent of compliance or non-compliance (both natural and man-related) with water quality standards (c) provide data which can be used to assess slow, long-term trends, as well as more transient pollution events, (d) determine the effectiveness of pollution control measures, (e) identify problems requiring corrective action before significant damage occurs, and (f) provide input to the design of corrective or mitigative actions.

4.2 Sampling Methods

One of the first considerations for a monitoring network is the type of measurements to be taken, continuous or periodic. General references in the literature suggest that the present state of the art is such that continuous monitoring techniques and instruments for water quality surveillance have a history of poor reliability under field conditions. This experience was well confirmed on the C-b Tract even though the best available equipment was used. Data from the continuous surface water instrumentation have been presented in the quarterly data reports and show many periods of interrupted operation. Continuous water level recorders for the deep wells also fared poorly. Almost every instrument developed malfunctions. Total reliance on the continuous recorders would have produced large gaps in the data. In light of this unsatisfactory performance, it is recommended that continuous measurements be eliminated for most parameters. Continuous monitoring is usually competitive or superior to periodic measurements only in the case of detecting violation of stream standards arising from accidental spills.

4.3 Sampling Frequency

Under natural conditions, the quality of both surface and ground water can change slowly, but perceptibly with time. In surface water systems, short-term perturbations are superimposed on long-term trends. Rates of change are related to rates of flow, which are determined by hydrogeologic considerations. Some ground water basins that are unaffected by man show annual fluctuations in quality caused by seasonal variations in precipitation, aquifer recharge, water table levels, and discharge rates. The influence of man and industrial development is usually marked as an increase in the amplitude of cyclical changes in quality along with a progressive decrease in average quality. The desirable frequency for monitoring water quality depends upon its sensitivity to natural and man-made influences and upon the pace of industrial development.

Frequency of sampling is a major consideration affecting the cost and reliability of information. The desirable frequency of sampling is a function of the variability of a parameter, the importance of that parameter, and the desired accuracy and precision of the estimates. In pollution monitoring, the sampling interval should be comparable to the half-life of a constituent.

If a water quality parameter exhibits a cyclic behavior, the time and frequency of sampling has to be selected appropriately so as to eliminate the possible bias introduced by periodic variation. For many water quality constituents, the most probable cyclic variations will have a period of one day, one week, one season, or one year. Sampling must be conducted more frequently than the period of any cycle which it is desired to detect. The frequency $f = h/2$, where h is the frequency of sampling, is known as the Nyquist frequency and is the highest frequency of variation which can be detected. To detect weekly variations, for example, at least two or preferably three equally spaced observations must be taken per week. The frequency of measurement in a trend network can often be lower, and the distances between sampling stations can be enlarged. The design of a trend network can be somewhat different depending on whether a step or ramp type change is expected.

Examining the baseline water quality data, no periodicity was indicated in the deep aquifers. Sampling can therefore be limited to the detection of long-term trends, in which case sampling once a year should be sufficient. Flow rates in springs and water levels in wells in the alluvium exhibit an annual cycle. Water quality in these sources does not show as clear a cyclic effect. Based on the Nyquist criterion, the minimum sampling frequency for these sources should be approximately three times a year. Surface streams which are heavily influenced by civilization may show weekly cycles. Surface streams near the C-b Tract probably do not exhibit this behavior, but short-term random fluctuations are much larger than in the springs and alluvial aquifers. In this case, the baseline frequency of sampling once a month may continue to be desirable, supplemented by continuous monitoring of some parameters.

Where effluents are being discharged directly and are subject to rapid changes in composition, weekly, daily, or continuous sampling may become appropriate. Wherever and whenever a pollution hazard develops, such as a toxic constituent in the ground water within a discharge area, the frequency of monitoring must be increased in accordance with the importance or seriousness of the situation.

One way to determine for a monitoring system either the number of sites or the frequency of sampling would be to specify a predetermined level of accuracy and precision. This can then be used to estimate the total sample size required from $n = (t/d)^2v$, where n is the sample size, t is the Students' t value for the specified confidence level, d is the chosen margin of error, and v is the variance of the parameter.

4.4 Sampling Sites

The desirable location of stations is dependent on the characteristics of the parameter being observed. Spatial resolution is related to temporal resolution. The longer the desired averaging interval, the fewer the number of stations required to depict the behavior of a given constituent.

The spatial distance over which a sampling station gives representative estimates of water quality will depend on the concentration gradients of the parameters. To achieve uniform spatial resolution, the sampling stations should be placed closer together in the areas of high concentration gradients and farther apart where spatial variation is small. In a multiparameter network, the design should be based on the parameter with the greatest rate of decay. The distance from a source to a sampling site should be such that the excess concentration is reduced by 50 percent. This distance corresponds to the half-life of excess concentration. For subsequent stations, the distance should be doubled each time.

The location of monitoring stations for surface water quality is a relatively straight-forward procedure when only a small drainage area is involved. Monitoring stations on each tributary of significance will make it possible to quickly pinpoint the source of any changes detected in the mainstream. If larger drainage areas are involved, then a rationale must be developed for placing the monitoring stations in specific locations. For the C-b Tract, however, the surface hydrology is defined rather simply in terms of the mainstem Piceance Creek, several ephemeral tributaries and two perennial tributaries, Willow Creek and Stewart Gulch. These stream elements completely encompass the surface drainage from the Tract. The four major gauging stations which presently define upstream and downstream Piceance plus the two perennial tributaries should therefore be retained as part of the permanent monitoring system.

Nothing in the Baseline data would suggest a reason for moving the locations of the surface water stations. In order to be flexible in response to development activities, however, some changes may be made in the future.

Because of the longer time scale involved in ground water movements (weeks or months may be required to move relatively short distances), the location of monitoring sites is more critical than for surface water in order to detect changes before significant degradation occurs in the system. Site selection must be based on a thorough knowledge of the area hydrology as well as on an analysis of the possible pollution sources.

Haphazard location of monitoring wells is certain to result in excessive costs and inadequate coverage. To provide general area coverage, the present network of alluvial wells should be maintained. Because the general hydraulic gradient found in the area slopes to the north, unless other local conditions are controlling, monitor wells should be placed to the north of possible pollution sources. Within local valleys, of course, wells should be placed downstream. Determining the number of wells required is not as simple as determining the number of stream gauging stations. Because of its small lateral dimensions and turbulent flow, a stream may be considered well-mixed, so that only a single sampling point is needed. Although an alluvial aquifer may be thought of as an underground river, it is far from well-mixed because of low velocities and stratified flow, and samples may be necessary at more than one point along a line perpendicular to the direction of flow. The further downstream the wells are placed from a suspected source, the fewer wells would be required. However, greater downstream distances imply longer time intervals before degradation could be detected, and therefore, a greater problem to deal with after detection.

The major change suggested by experience accumulated in the baseline program would be to change the alluvial well configurations to allow sampling from different depths within the saturated interval. The lack of a correlation between water level cycles and aquifer water quality, along with a consideration of the well completion designs, suggests that the samples are being pulled only from the bottom of the saturated zone and therefore are not truly representative of average conditions in the aquifer. A similar recommendation with respect to the deep aquifers would be either to modify some existing wells or else drill some new wells to monitor conditions in the Uinta Formation exclusively. Key questions for which answers could not be obtained by analyzing the baseline data concern the extent of aquifer recharge occurring on Tract and the source of major spring flows. Specific data for the uppermost water-bearing zones could aid in obtaining these answers.

4.5 Selection of Parameters

Selection of water quality parameters to be monitored should be based on an analysis of possible pollutants or quality changes and should focus on specific constituents chosen because of their hazardous character, persistence, concentration, ease of identification, or other pertinent characteristics. It is felt that the major probability for direct surface water degradation is increased erosion and sediment loads resulting from construction activities. Thus, special attention should be given to maintaining sediment records at all stations. In addition to suspended sediment, total dissolved solids (as reflected by electrical conductivity) and turbidity are important parameters. These three measurements are sufficient to record a major change in the solids loading of a stream due to increased erosion or to runoff or leaching from piled solids. To determine the nature and source of the solids and their effect on stream biology, such standard measures as temperature, dissolved oxygen, pH, hardness, alkalinity, and major ion concentrations should also be determined on a routine basis.

Detection of spills and leaks of oil and other organic materials would be accomplished by normal analyses for oil and grease, and for dissolved and suspended organic carbon. Pollution via runoff from paved areas would also show up in these analyses. Fractionation of the dissolved organic carbon can be used to help identify classes or origins of pollutants.

Analyses for trace elements should be designed in accordance with possible sources which can be defined. Examination of the geochemical and hydrological characteristics of the C-b resource reveals that the elements fluorine and arsenic are of special significance. Fluoride is present in high concentrations in all the deep aquifers under C-b. Thus, any surface water changes resulting from mine inflow water reaching the surface via leakage from well injection systems, holding reservoirs, etc., will be immediately apparent as an increase in fluoride levels. Fluoride in water is normally conservative, that is, it does not change in concentration readily by natural processes such as sorption and chemical reactions. There is such a strong contrast between surface and deep aquifer waters with regard to this element that no other identification of the source of change would be necessary in most cases.

Arsenic is present in oil shale and in crude shale oil prior to hydrotreating. To ensure that no environmental pollution occurs, monitoring for arsenic should be conducted routinely. Arsenic could be emitted to the atmosphere via process stacks, and air quality regulations will require stack monitoring as the primary means of regulating these emissions. Arsenic in surface waters could result from secondary sources via fallout or washout of atmospheric emissions. Unexpected leaching from piled shale might also result in increased arsenic levels. Other trace elements of interest besides fluorine and arsenic may be defined later.

Another category of trace contaminants which appears to be of concern is polycyclic organic matter (POM). These materials, some of which are known to be carcinogenic, can be found in trace quantities in both raw and processed shale. Continued surveillance of surface waters should be conducted to detect possible pollution from wind-blown dust off the shale piles, from percolation and seepage, or from process units. Major changes should be picked up by the organic carbon fractionation procedure. Unfortunately, this procedure is still in the developmental stage, and its powers of discrimination are largely unknown.

Many measures of surface water quality which would be standard in other circumstances such as pesticide and herbicide levels and coliform counts, will have little relevancy for monitoring the C-b Project.

In order for a given parameter to be useful in detecting environmental changes, the accuracy of the data must be such that the minimum increment which it is desired to detect can be statistically differentiated from random fluctuations. Those parameters which cannot be distinguished with a satisfactory level of confidence are of little value.

Monitoring parameters can be grouped into three categories ("Quantitative Methods for Preliminary Design of Water Quality Surveillance Systems," EPA-R5-72-001, 1972): (a) conservative, (b) non-conservative non-coupled, and (c) non-conservative coupled. A constituent can be classed as conservative if it does not interact with the environment and remains unaffected by the physical, chemical, or biological forces. There is probably no constituent which satisfies these requirements completely, although some may come close to doing so. Chloride, fluoride, some heavy metals, and non-degradable pesticides belong to this group. There is no self-purification of water systems with respect to these constituents. They either remain indefinitely in the immediate environment or are discharged to the sea. In determining the fate of such materials, environmental factors (such as temperature and pH) are not normally important. Only the processes of dilution, sedimentation, diffusion, biological uptake and transport are relevant.

Non-conservative constituents are affected, in addition, by degradation, decay, and adsorption. If their behavior is not influenced by any other parameter, they can be classed as non-coupled. Examples are coliforms, temperature, BOD, phenols, and turbidity.

Changes in the concentration of a coupled, non-conservative constituent are affected also by one or more other observed parameters. Dissolved oxygen is an example because it is also influenced by the changes in BOD.

It has been concluded ("Strategies for Water Quality Monitoring," PB-245765, 1975) that significant coupling between parameters in stream flows is not widespread and that the determination of coupling coefficients is of little value in pruning a list of monitoring parameters. Furthermore, such correlations as do exist are location specific and often cannot be transferred to other sites. One exception is a generally useful coupling, that of dissolved solids with conductivity. As illustrated by several graphs presented in this report, conductivity can serve as an effective index of concentration for a number of constituents. It was not felt that an attempt to determine other coupling coefficients would be useful with regard to selecting parameters for the monitoring program.

Emphasis must of course also be placed on measuring those parameters that are specified in water quality standards. Requirements for the revised Colorado standards were listed in the sections on water quality. Particular pollutants which result from industrial or other discharges need be included in a monitoring scheme only in those stream segments which receive discharges from such sources. A general list of important parameters for different uses is given in Table 4-1 ("Strategies for Water Quality Monitoring" PB-245765, 1975). Such a list, in conjunction with the water quality standards, can be used to design a particular monitoring program.

The C-b Baseline Program was designed from such general considerations. In designing an on-going monitoring program, it is desirable to attempt both scientific and economic optimization by building upon the experience of the baseline program. In the absence of an economic optimization objective, the information content of a monitoring network can be used to obtain a relative ranking of data sets. The information content may be represented by n/s^2, where n is the number of observations and s the standard deviation of the sample. Thus large sample deviations may be offset by greater numbers of samples. Using historical data, the sampling frequency at each sampling location in a monitoring network can be adjusted so as to give equal information content for a particular parameter. This method of optimization does not appear attractive except for systems covering a very large geographical area, because each sampling station would require a different sampling schedule.

A method of selecting the most desirable parameters for continued monitoring is to examine the variability of the data. A measure of the variability of a sample is given by the coefficient of variation, $CV = s/m$, where m is the mean. The smaller the coefficient of variation, the more precise the data. All other factors being equal, a parameter determined with more precision should be more valuable and would be kept in a monitoring program in preference to another parameter with a larger CV.

A ranking of chemical constituents in ground water with respect to coefficient of variation as determined by the baseline data, is given in Tables 4-2, 4-3, and 4-4. The magnitude of CV generally increases to the right in these tables, indicating the greater variability of samples from deeper ground water sources. Presumably a constituent which appears consistently near the bottom of the list in all four columns should be assigned a low priority for future work. Variability is only one measure of usefulness, of course, and

Table 4-1

IMPORTANT PARAMETERS FOR DIFFERENT USES

	Parameter	Use
1.	Temperature	Aquatic life, Industrial use, Assimilative capacity, Recreation
2.	Turbidity	Drinking water, Recreation, Industrial use, Aquatic life
3.	pH	Industrial use, Aquatic life, Recreation
4.	Dissolved Oxygen	Aquatic life, Aesthetics, Industrial use, Assimilative capacity
5.	BOD	Food and beverage industries, Recreation, Assimilative capacity
6.	Suspended Solids	Aesthetics, Photosynthesis, Reservoir capacity depletion, Hydroelectric power generation, Navigation
7.	Total Dissolved Solids	Irrigation, Water supply, Industrial use
8.	Coliform	Direct-contact water-based recreation, Water supply, Food and beverage industries, Irrigation
9.	Nutrients	Eutrophication, Aesthetic degradation, Secondary effects on aquatic life
10.	Organics	Water supply, Industrial use, Aquatic life
11.	Heavy Metals	Water supply, Aquatic life
12.	Radioactivity	Water supply
13.	Oil	Recreation, Industrial use
14.	Iron and Manganese	Water supply, Industrial use
15.	Chlorides and Sulfates	Water supply, Industrial use
16.	Hardness	Industrial use, Aquatic life
17.	Phenols	Water supply
18.	MBAS	Water supply, Industrial use
19.	Color	Aesthetics, Water supply, Recreation, Industrial use
20.	Conductivity	General parameter of water quality
21.	Chlorophyll	Biological activity

Table 4-2 COEFFICIENT OF VARIATION OF MAJOR CONSTITUENTS

Streams		Springs and Seeps		Alluvial Wells		Upper Aquifer		Lower Aquifer	
Calcium	.11	Bicarbonate	.16	Bicarbonate	.17	Silica	.35	Silica	.54
Silica	.14	Sulfate	.18	Sulfate	.22	Bicarbonate	.66	Phosphate	1.1
Sulfate	.14	Silica	.19	Magnesium	.22	Phosphate	.67	Sulfate	1.5
Bicarbonate	.15	Sodium	.22	Silica	.24	Sodium	.75	Nitrate	1.6
Sodium	.17	Magnesium	.23	Calcium	.31	Sulfate	.77	Bicarbonate	1.7
Chloride	.22	Calcium	.29	Potassium	.40	Calcium	.87	Potassium	1.7
Magnesium	.23	Potassium	.36	Sodium	.49	Carbonate	.87	Sodium	1.9
Potassium	.59	Chloride	.55	Chloride	.64	Magnesium	.95	Magnesium	1.9
Ammonia	.99	Phosphate	.80	Carbonate	.81	Potassium	1.0	Carbonate	2.2
Nitrate	1.2	Ammonia	.83	Phosphate	1.0	Ammonia	1.1	Chloride	2.2
Phosphate	1.7	Carbonate	1.1	Nitrate	1.2	Nitrate	1.4	Calcium	2.4
Carbonate	4.1	Nitrate	1.1	Ammonia	3.6	Chloride	2.7	Ammonia	2.5

Table 4-3 COEFFICIENT OF VARIATION OF IMPORTANT TRACE ELEMENTS

Streams		Springs and Seeps		Alluvial Wells		Upper Aquifer		Lower Aquifer	
Boron	0.2	Barium	0.5	Nickel	1.0	Vanadium	0.5	Fluoride	0.5
Arsenic	0.7	Vanadium	0.8	Copper	1.0	Manganese	1.0	Manganese	0.9
Fluoride	0.7	Fluoride	0.9	Cobalt	1.2	Cobalt	1.0	Nickel	1.0
Aluminum	0.8	Lead	1.0	Fluoride	1.3	Lead	1.0	Cobalt	1.2
Copper	1.0	Nickel	1.0	Barium	1.4	Barium	1.0	Aluminum	1.3
Iron	1.0	Zinc	1.0	Lead	1.5	Arsenic	1.0	Arsenic	1.5
Manganese	1.3	Boron	1.2	Boron	1.6	Nickel	1.5	Mercury	1.8
Zinc	1.5	Mercury	1.2	Arsenic	1.7	Boron	1.9	Lead	2.0
Mercury	2.0	Copper	1.2	Iron	1.7	Mercury	2.0	Vanadium	2.0
Barium	2.6	Manganese	1.3	Aluminum	2.0	Zinc	2.0	Barium	2.1
		Cobalt	1.4	Zinc	2.0	Aluminum	2.3	Iron	2.2
		Aluminum	1.5	Manganese	2.5	Iron	2.4	Copper	2.3
		Arsenic	2.0	Vanadium	3.0	Fluoride	2.6	Boron	2.8
		Iron	3.0	Mercury	3.3	Copper	4.4	Zinc	3.0

Table 4-4 COEFFICIENT OF VARIATION OF MINOR TRACE ELEMENTS

Springs and Seeps		Alluvial Wells		Upper Aquifer		Lower Aquifer	
Strontium	0.5	Strontium	0.6	Rubidium	0.5	Scandium	0.8
Scandium	0.8	Scandium	0.8	Scandium	0.7	Molybdenum	1.0
Rubidium	1.0	Bromine	0.8	Molybdenum	1.0	Strontium	1.6
Titanium	1.0	Molybdenum	0.8	Strontium	1.1	Titanium	2.0
Bromine	1.0	Rubidium	1.0	Bromine	1.3	Iodine	2.3
Molybdenum	1.3	Iodine	1.0	Zirconium	1.5	Zirconium	2.5
Zirconium	1.8	Titanium	1.3	Iodine	1.7	Rubidium	2.9
Iodine	2.0	Zirconium	1.4	Titanium	3.0	Bromine	3.0

such factors as importance to water quality standards and usefulness as indicators and correlating relationships must also be considered. It is suggested that these tables will be of value in discussions concerning the exact parameters to be included in the monitoring program.

One caution should be exercised. Many statistical methods are based upon the assumption of a normal distribution of data. Many of the water quality parameters expressed as concentrations show the following characteristics:

(a) The parameters have a finite range. They have a fixed lower physical limit, in most cases equal to zero, and a variable but finite upper limit, such as saturation concentration.

(b) The distribution is typically positively skewed.

(c) The parameters exhibit a periodic behavior. The periodicity may be due either to an annual cycle in the meterological and hydrological environment, or to weekly and seasonal cycles in the inputs to the system.

A blanket assumption that all water quality parameters follow a symmetric normal distribution is highly unjustified and the statistical treatment and interpretation of data must recognize this fact.

APPENDIX

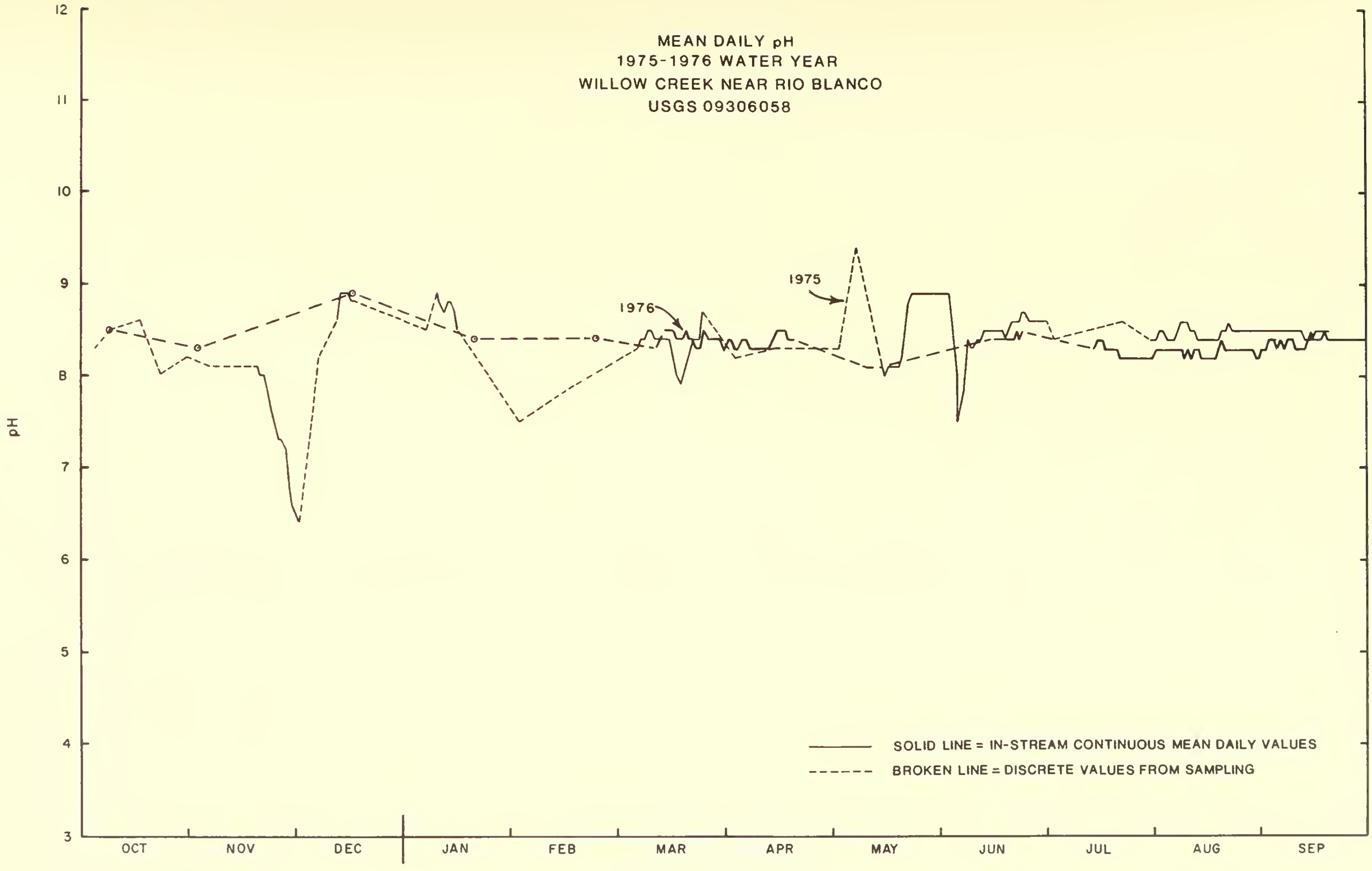
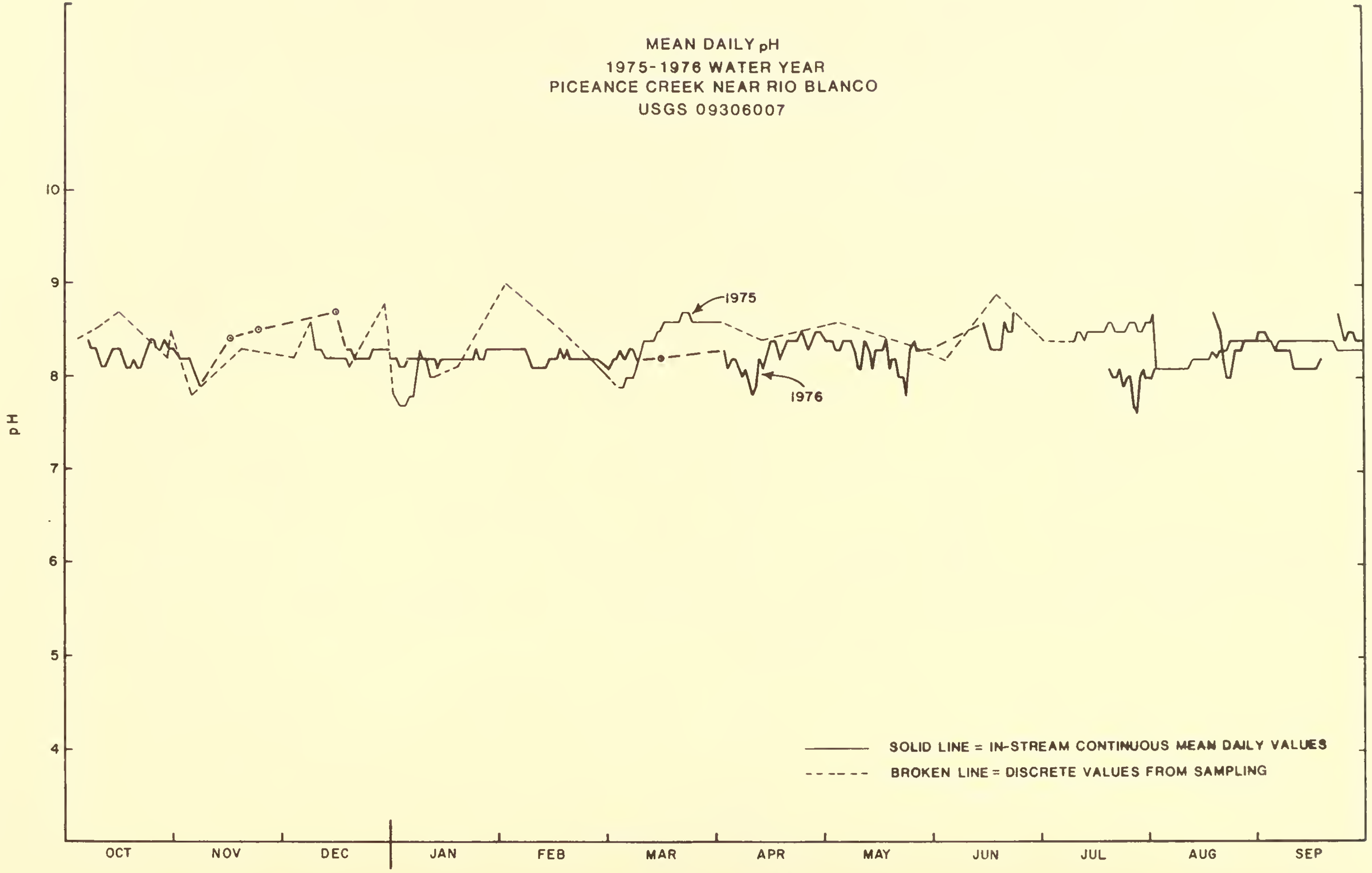

MEAN DAILY pH
1975-1976 WATER YEAR
WILLOW CREEK NEAR RIO BLANCO
USGS 09306058
pH
12
11
10
9
8
7
6
5
4
3
1975
1976
SOLID LINE = IN-STREAM CONTINUOUS MEAN DAILY VALUES
BROKEN LINE = DISCRETE VALUES FROM SAMPLING
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
TIME OF THE YEAR

FIGURE A-1



MEAN DAILY pH
1975-1976 WATER YEAR
PICEANCE CREEK NEAR RIO BLANCO
USGS 09306007

FIGURE A-2

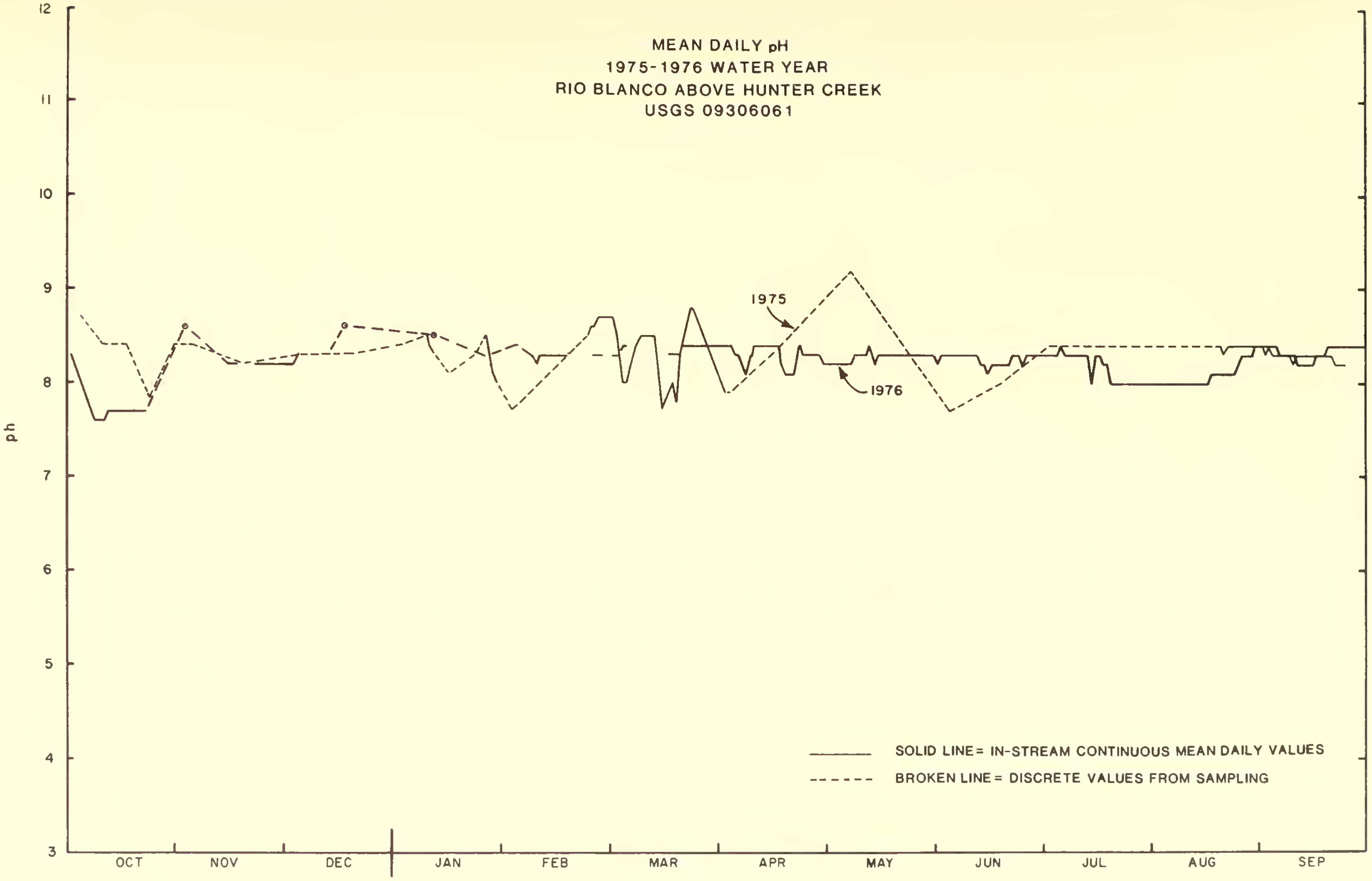

MEAN DAILY pH
1975-1976 WATER YEAR
RIO BLANCO ABOVE HUNTER CREEK
USGS 09306061
pH
12
11
10
9
8
7
6
5
4
3
1975
1976
SOLID LINE = IN-STREAM CONTINUOUS MEAN DAILY VALUES
BROKEN LINE = DISCRETE VALUES FROM SAMPLING
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
TIME OF THE YEAR

FIGURE A-3

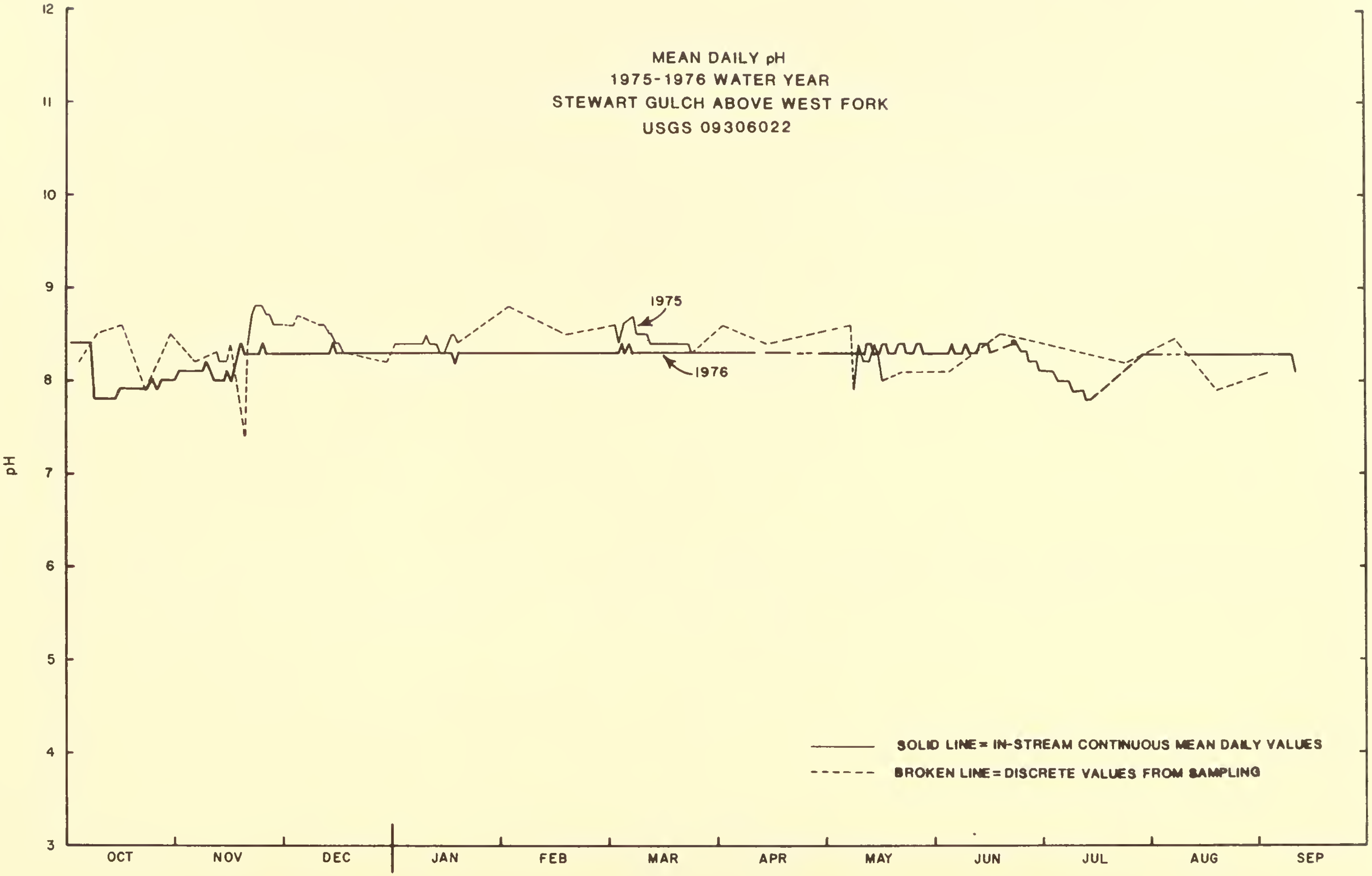

MEAN DAILY pH
1975-1976 WATER YEAR
STEWART GULCH ABOVE WEST FORK
USGS 09306022
pH
12
11
10
9
8
7
6
5
4
3
1975
1976
SOLID LINE = IN-STREAM CONTINUOUS MEAN DAILY VALUES
BROKEN LINE = DISCRETE VALUES FROM SAMPLING
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
TIME OF THE YEAR

FIGURE A-4

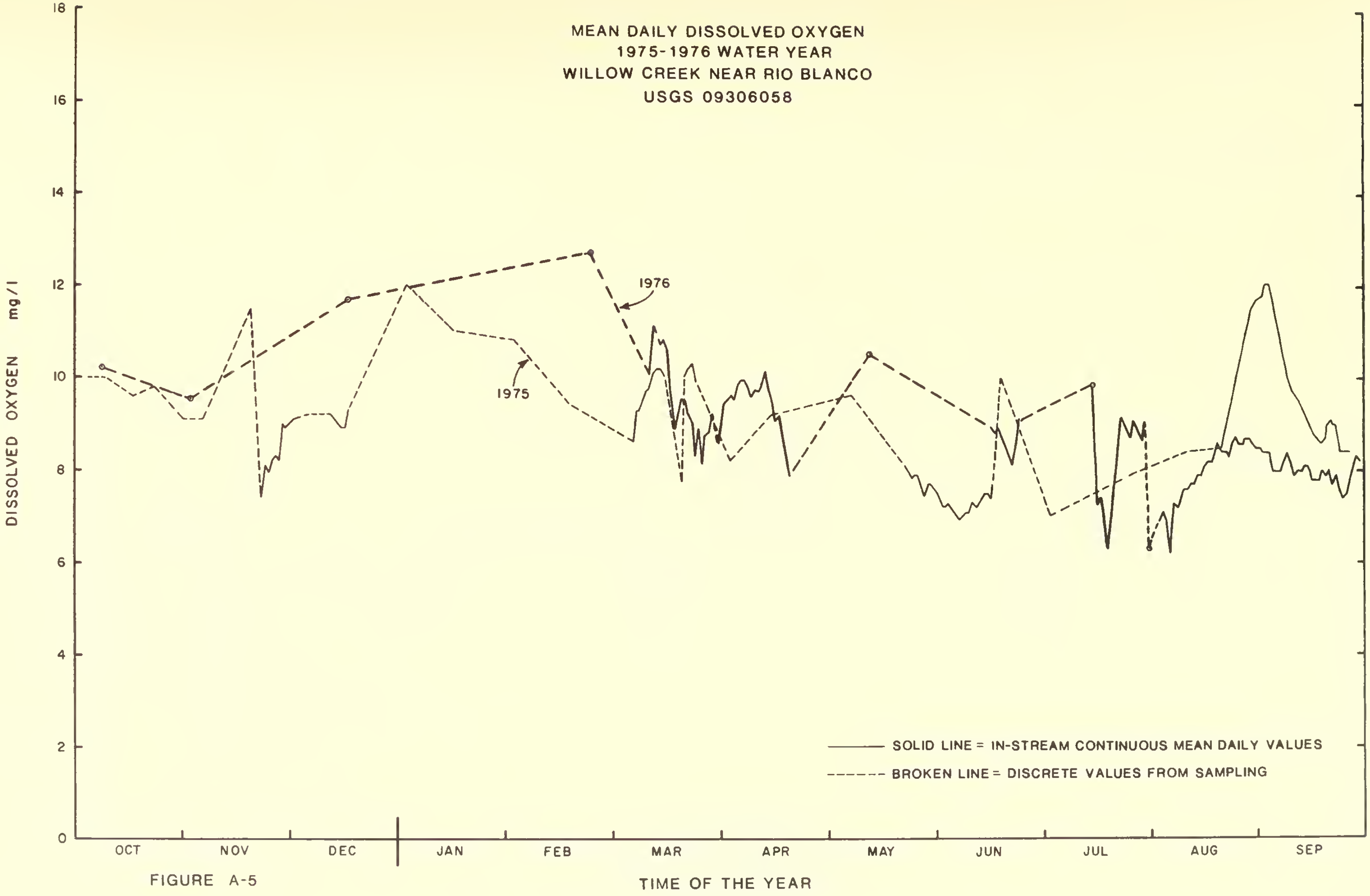

MEAN DAILY DISSOLVED OXYGEN
1975-1976 WATER YEAR
WILLOW CREEK NEAR RIO BLANCO
USGS 09306058
DISSOLVED OXYGEN mg/l
18
16
14
12
10
8
6
4
2
0
1976
1975
SOLID LINE = IN-STREAM CONTINUOUS MEAN DAILY VALUES
BROKEN LINE = DISCRETE VALUES FROM SAMPLING
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
TIME OF THE YEAR

FIGURE A-5

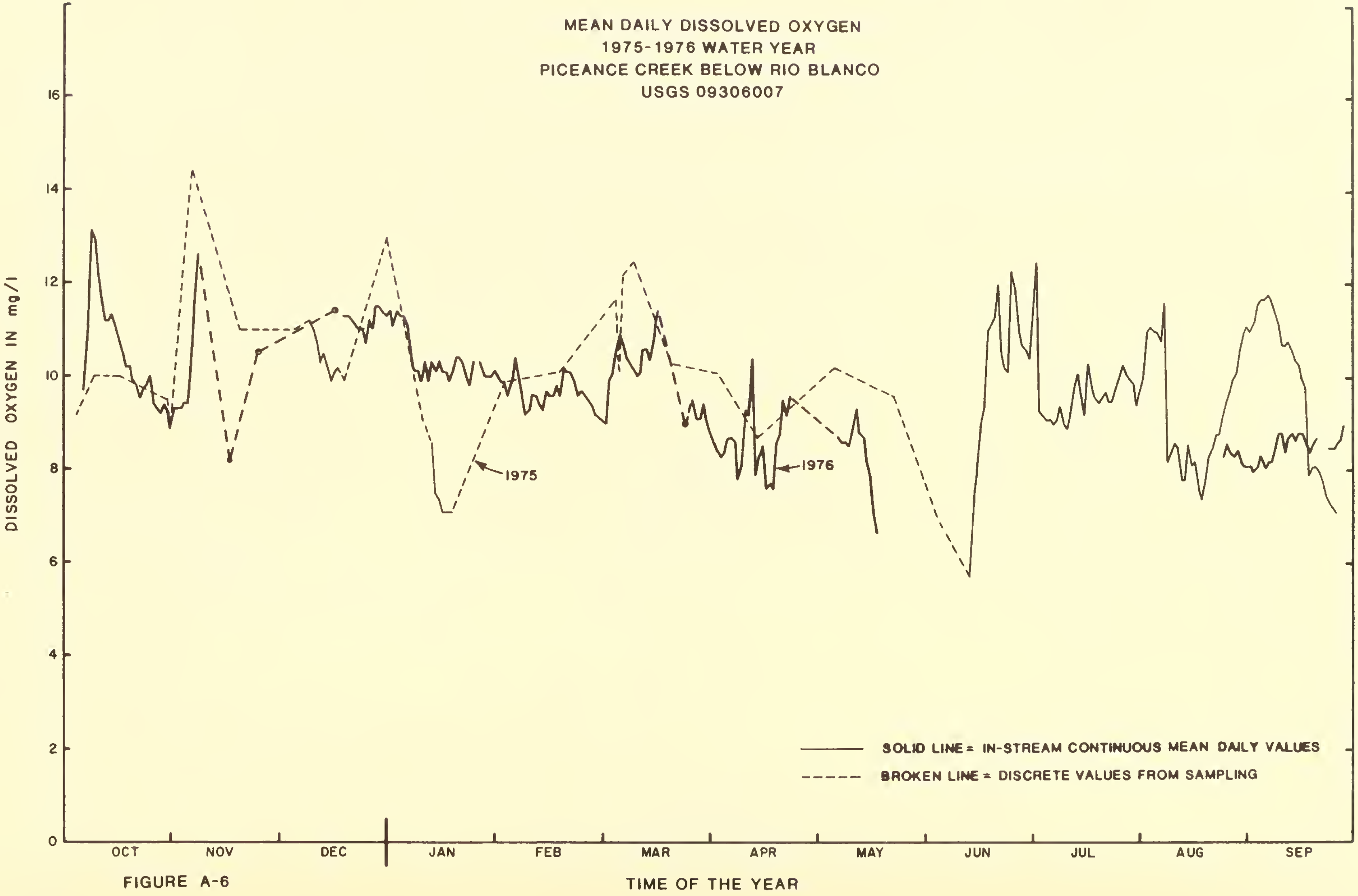

MEAN DAILY DISSOLVED OXYGEN
1975-1976 WATER YEAR
PICEANCE CREEK BELOW RIO BLANCO
USGS 09306007
DISSOLVED OXYGEN IN mg/l
0
2
4
6
8
10
12
14
16
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
TIME OF THE YEAR
1975
1976
SOLID LINE = IN-STREAM CONTINUOUS MEAN DAILY VALUES
BROKEN LINE = DISCRETE VALUES FROM SAMPLING

FIGURE A-6

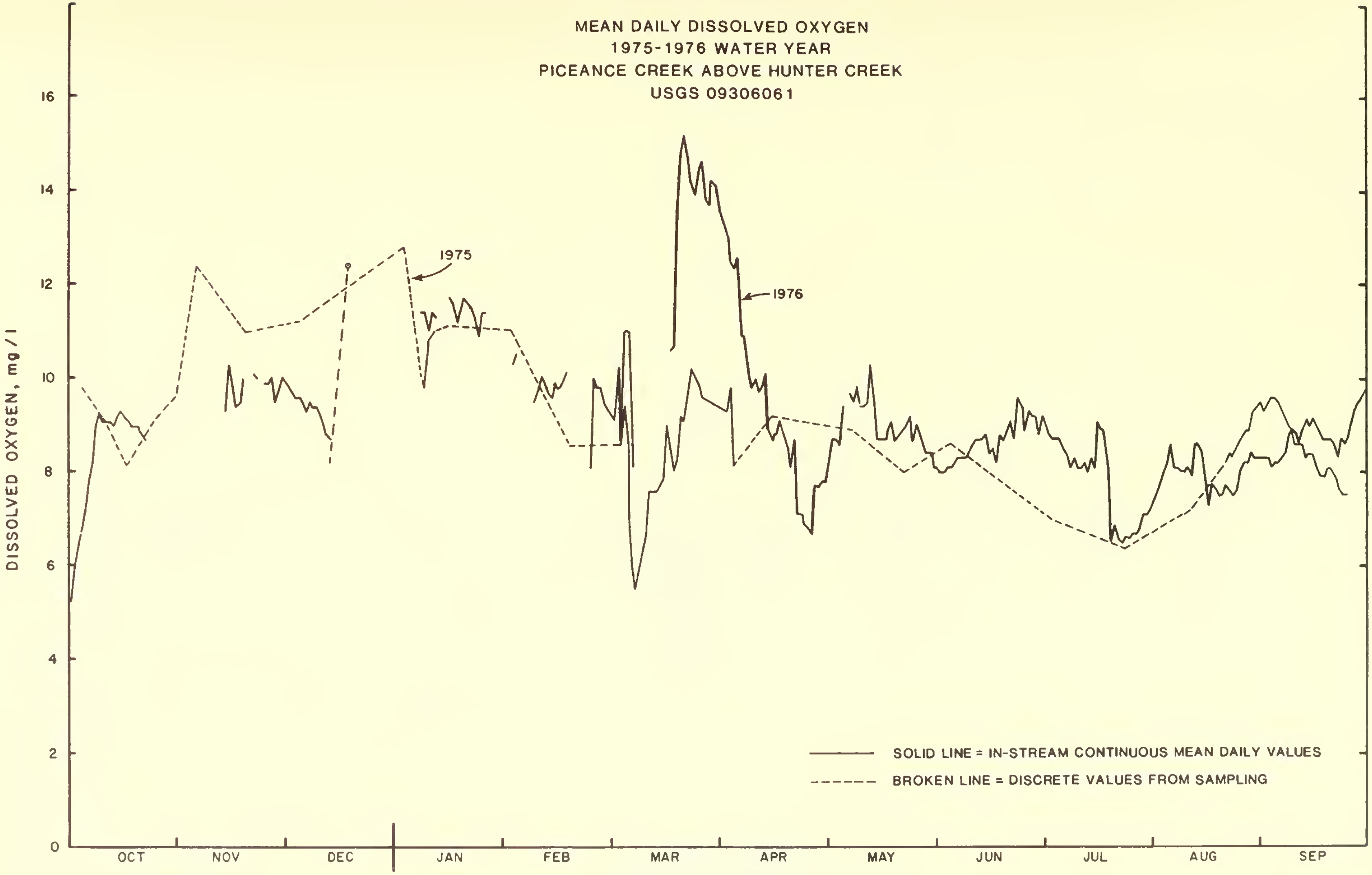
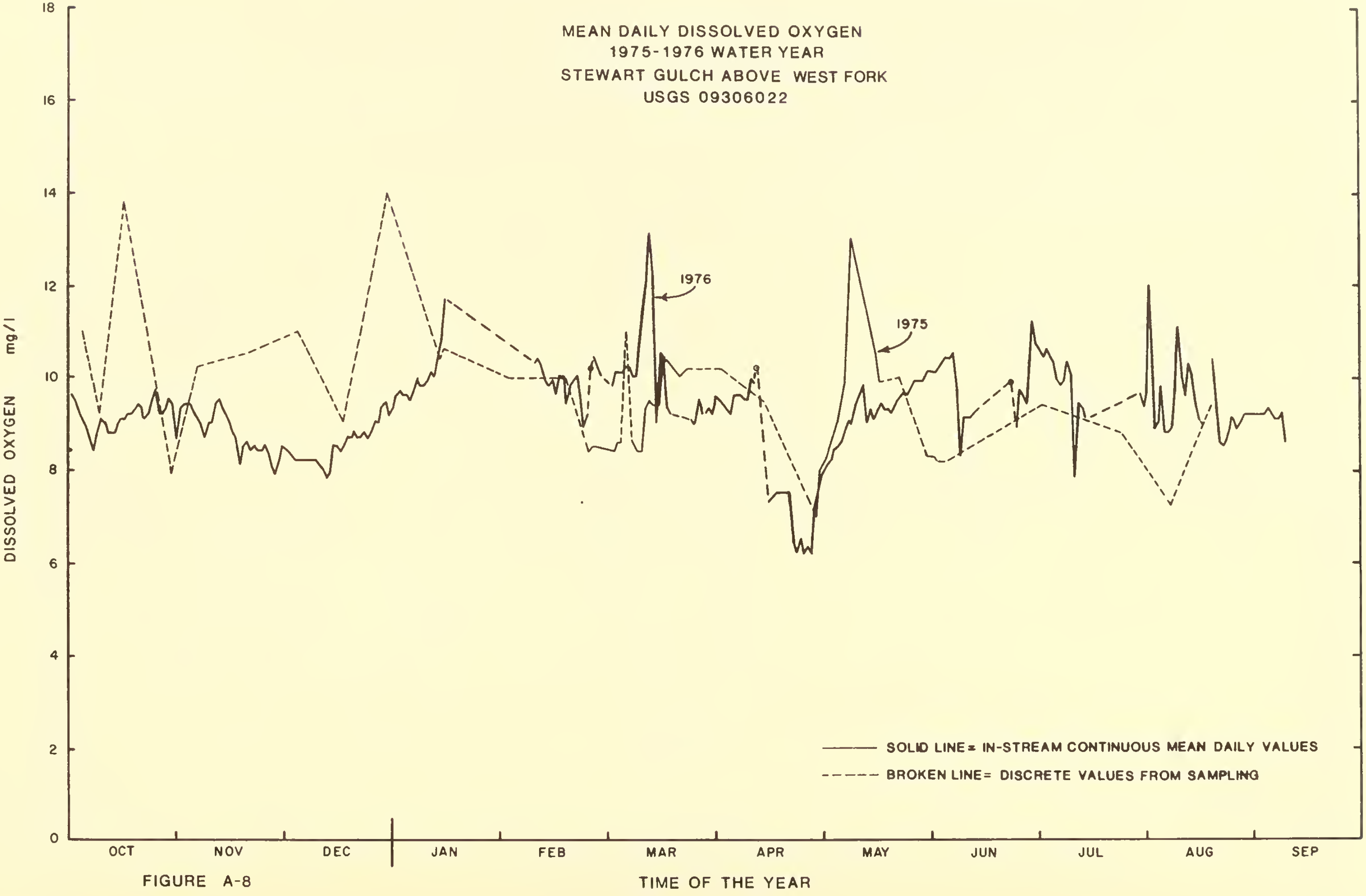
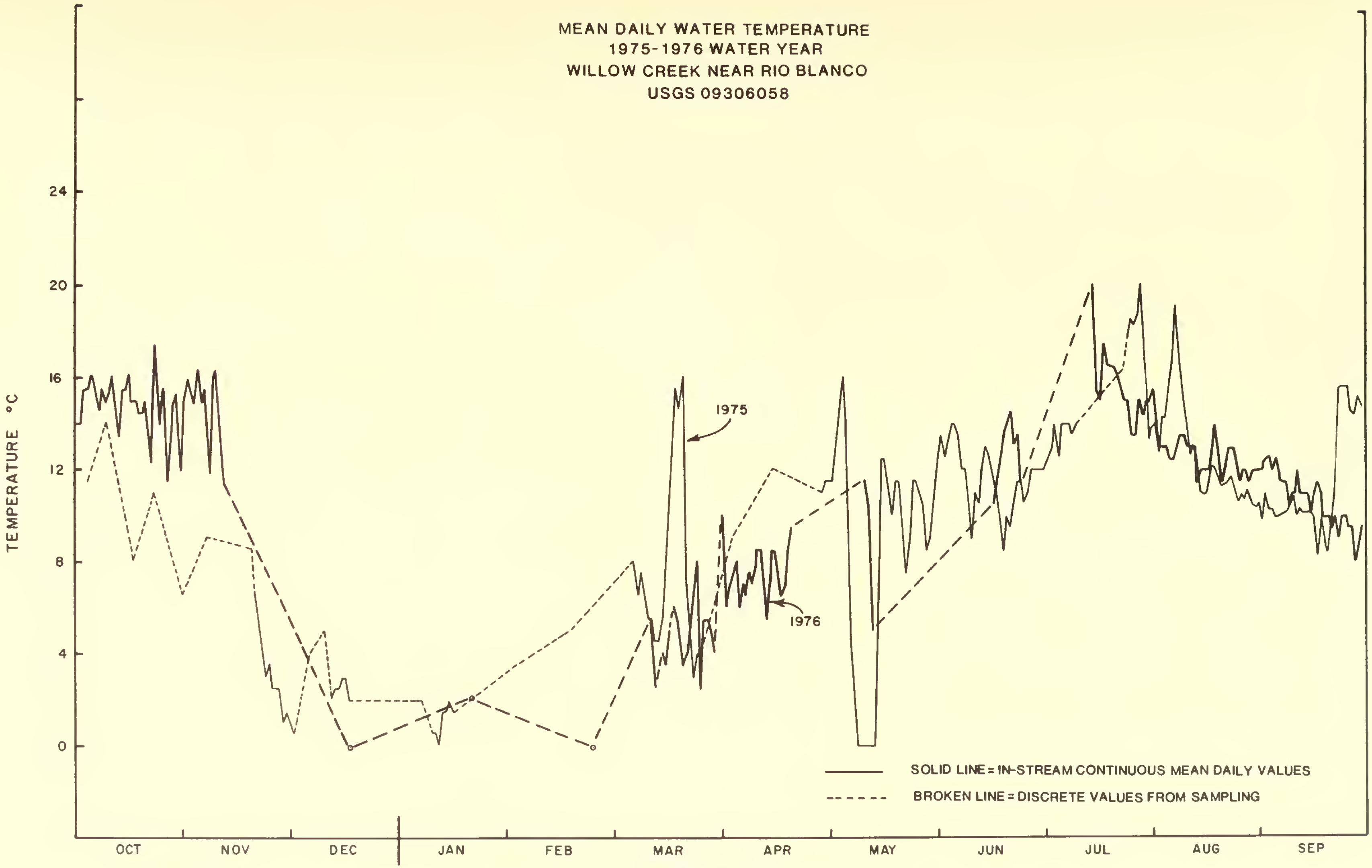

MEAN DAILY DISSOLVED OXYGEN
1975-1976 WATER YEAR
PICEANCE CREEK ABOVE HUNTER CREEK
USGS 09306061
DISSOLVED OXYGEN, mg/l
0
2
4
6
8
10
12
14
16
1975
1976
SOLID LINE = IN-STREAM CONTINUOUS MEAN DAILY VALUES
BROKEN LINE = DISCRETE VALUES FROM SAMPLING
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
TIME OF THE YEAR

FIGURE A-7



MEAN DAILY DISSOLVED OXYGEN
1975-1976 WATER YEAR
STEWART GULCH ABOVE WEST FORK
USGS 09306022

FIGURE A-8



MEAN DAILY WATER TEMPERATURE
1975-1976 WATER YEAR
WILLOW CREEK NEAR RIO BLANCO
USGS 09306058

FIGURE A-9

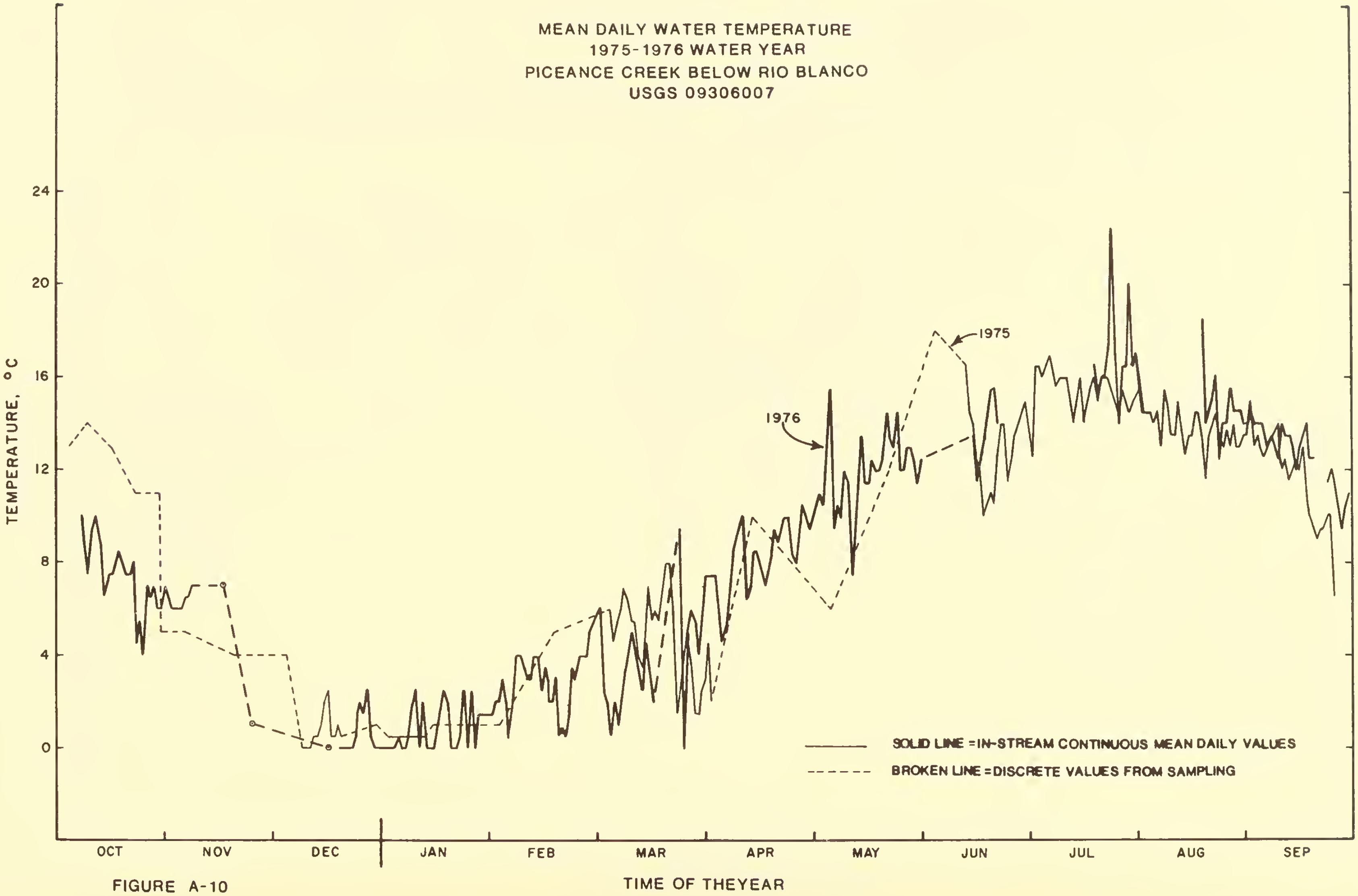

MEAN DAILY WATER TEMPERATURE
1975-1976 WATER YEAR
PICEANCE CREEK BELOW RIO BLANCO
USGS 09306007
TEMPERATURE, °C
24
20
16
12
8
4
0
1975
1976
SOLID LINE = IN-STREAM CONTINUOUS MEAN DAILY VALUES
BROKEN LINE = DISCRETE VALUES FROM SAMPLING
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
TIME OF THEYEAR

FIGURE A-10

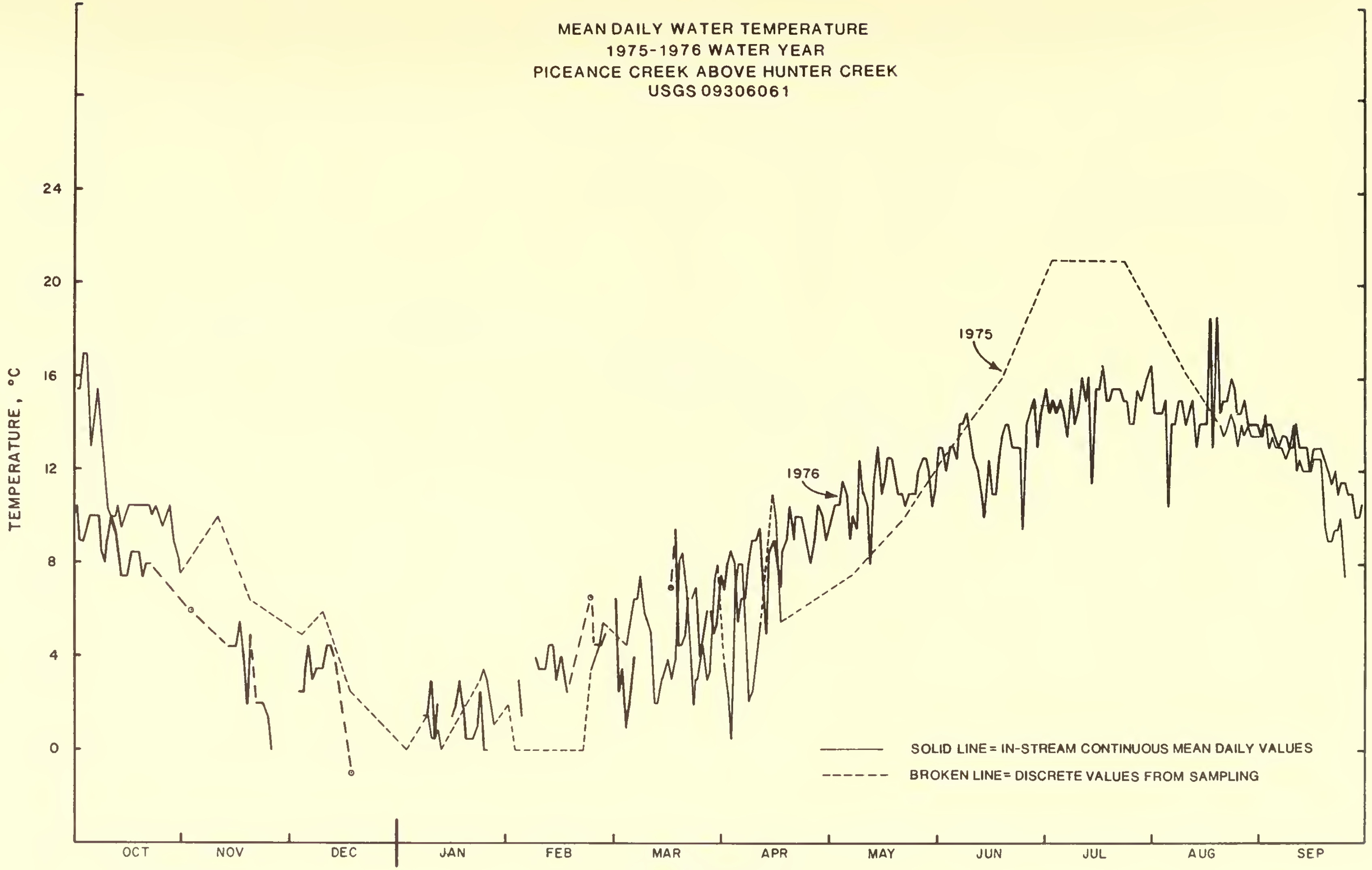
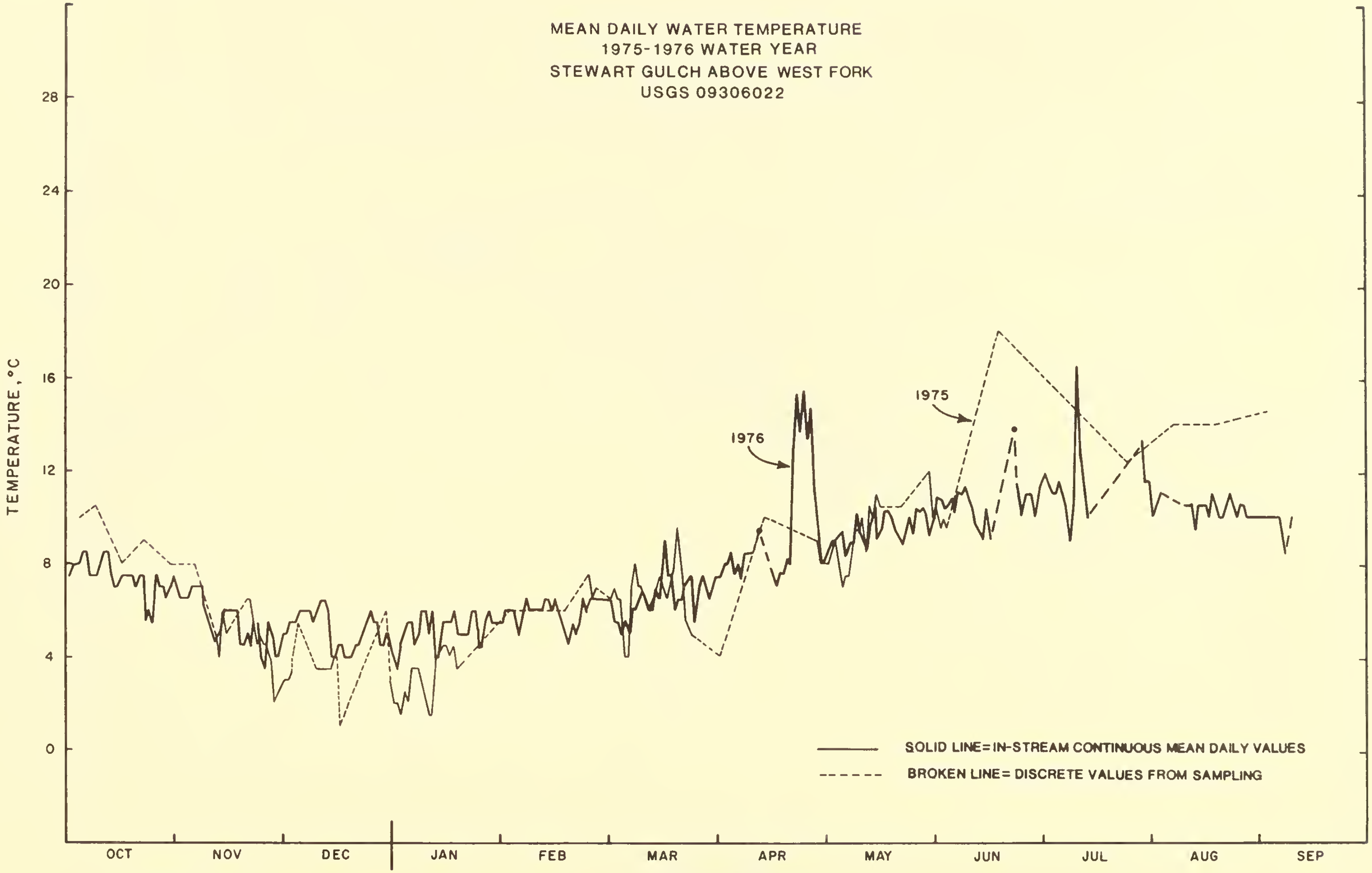

MEAN DAILY WATER TEMPERATURE
1975-1976 WATER YEAR
PICEANCE CREEK ABOVE HUNTER CREEK
USGS 09306061

FIGURE A-11



MEAN DAILY WATER TEMPERATURE
1975-1976 WATER YEAR
STEWART GULCH ABOVE WEST FORK
USGS 09306022

FIGURE A-12

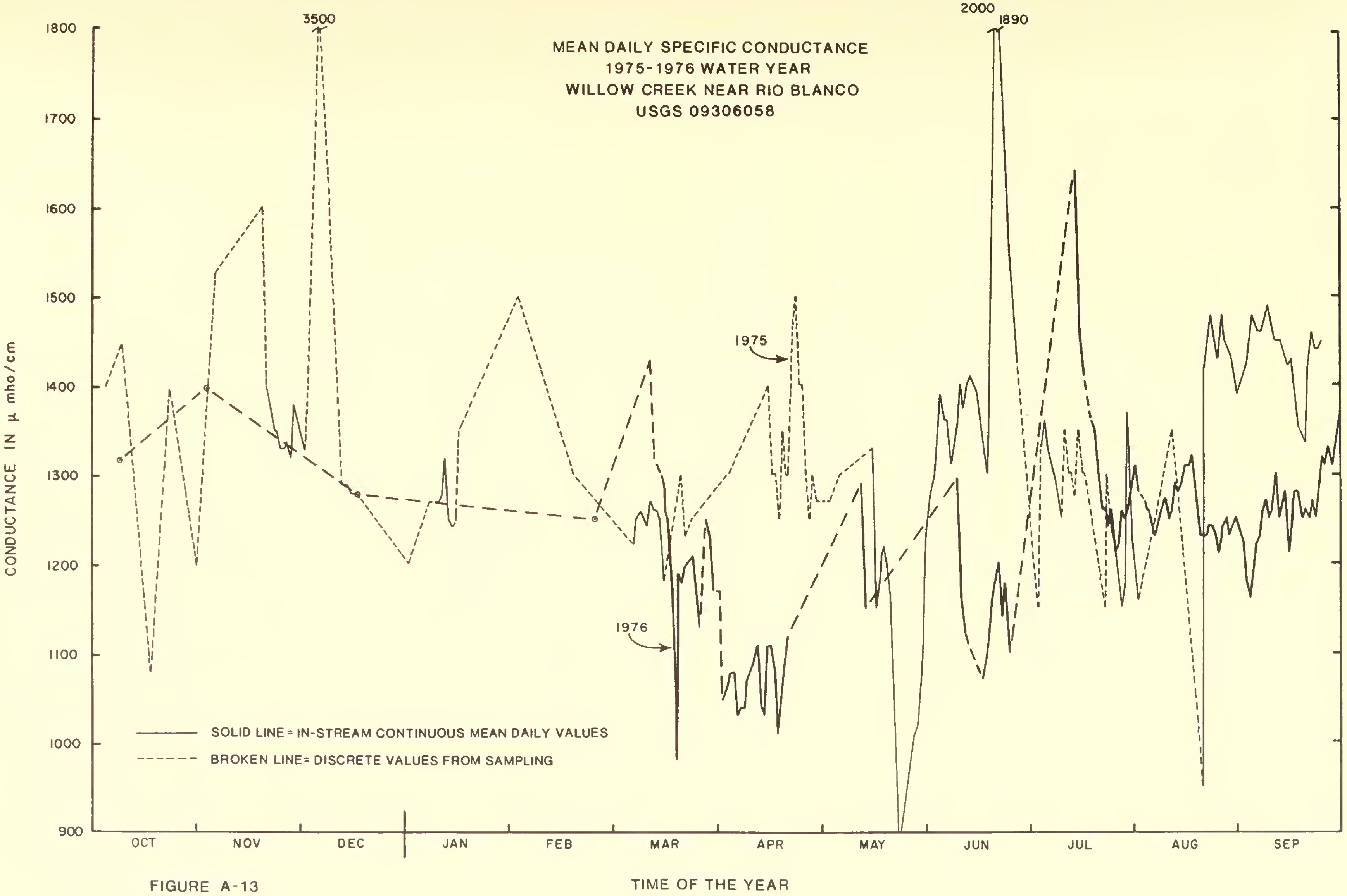
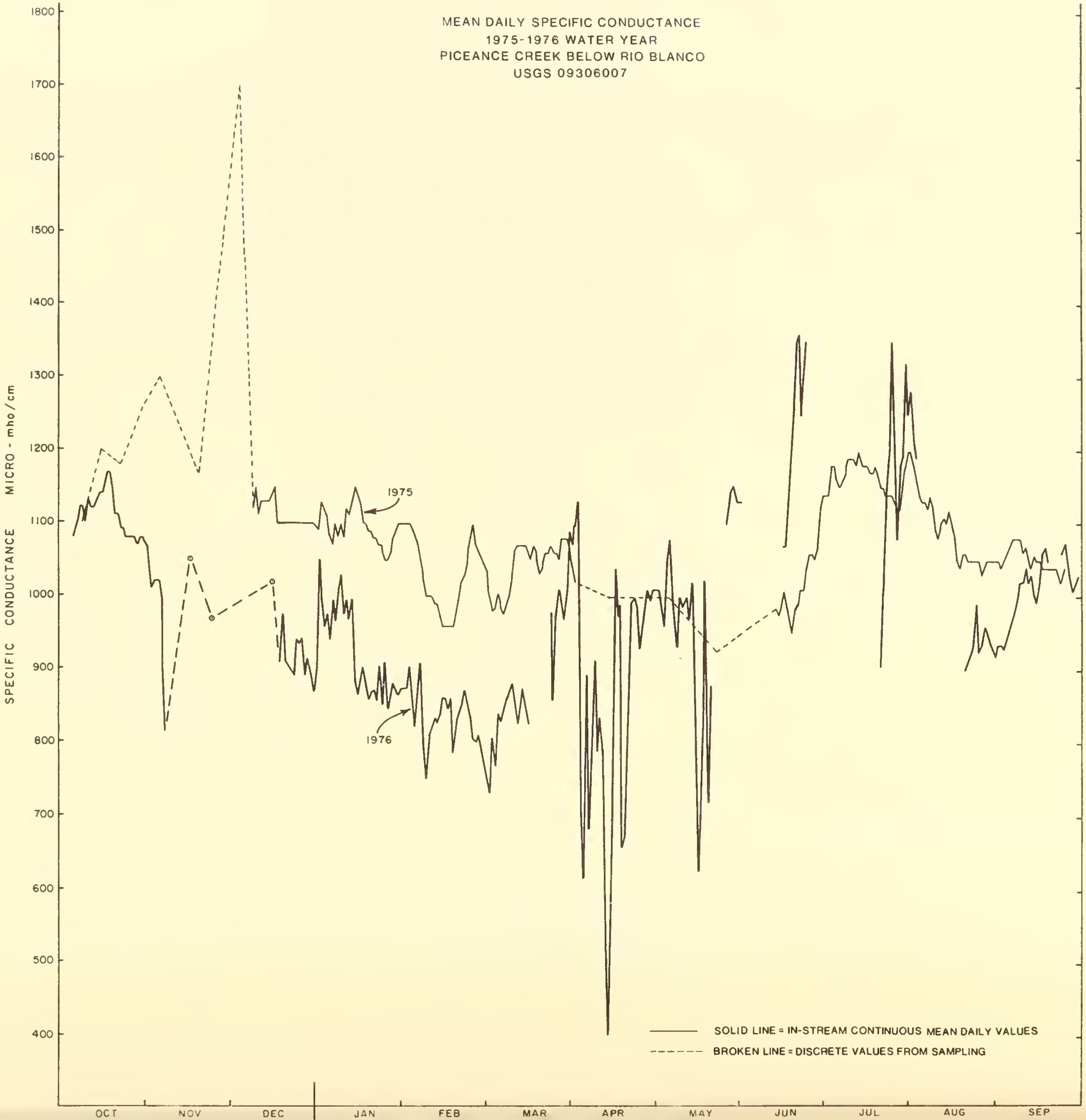

MEAN DAILY SPECIFIC CONDUCTANCE
1975-1976 WATER YEAR
WILLOW CREEK NEAR RIO BLANCO
USGS 09306058
3500
2000
1890
1975
1976
SOLID LINE = IN-STREAM CONTINUOUS MEAN DAILY VALUES
BROKEN LINE = DISCRETE VALUES FROM SAMPLING
CONDUCTANCE IN µ mho/cm
1800
1700
1600
1500
1400
1300
1200
1100
1000
900
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
TIME OF THE YEAR

FIGURE A-13



MEAN DAILY SPECIFIC CONDUCTANCE
1975-1976 WATER YEAR
PICEANCE CREEK BELOW RIO BLANCO
USGS 09306007

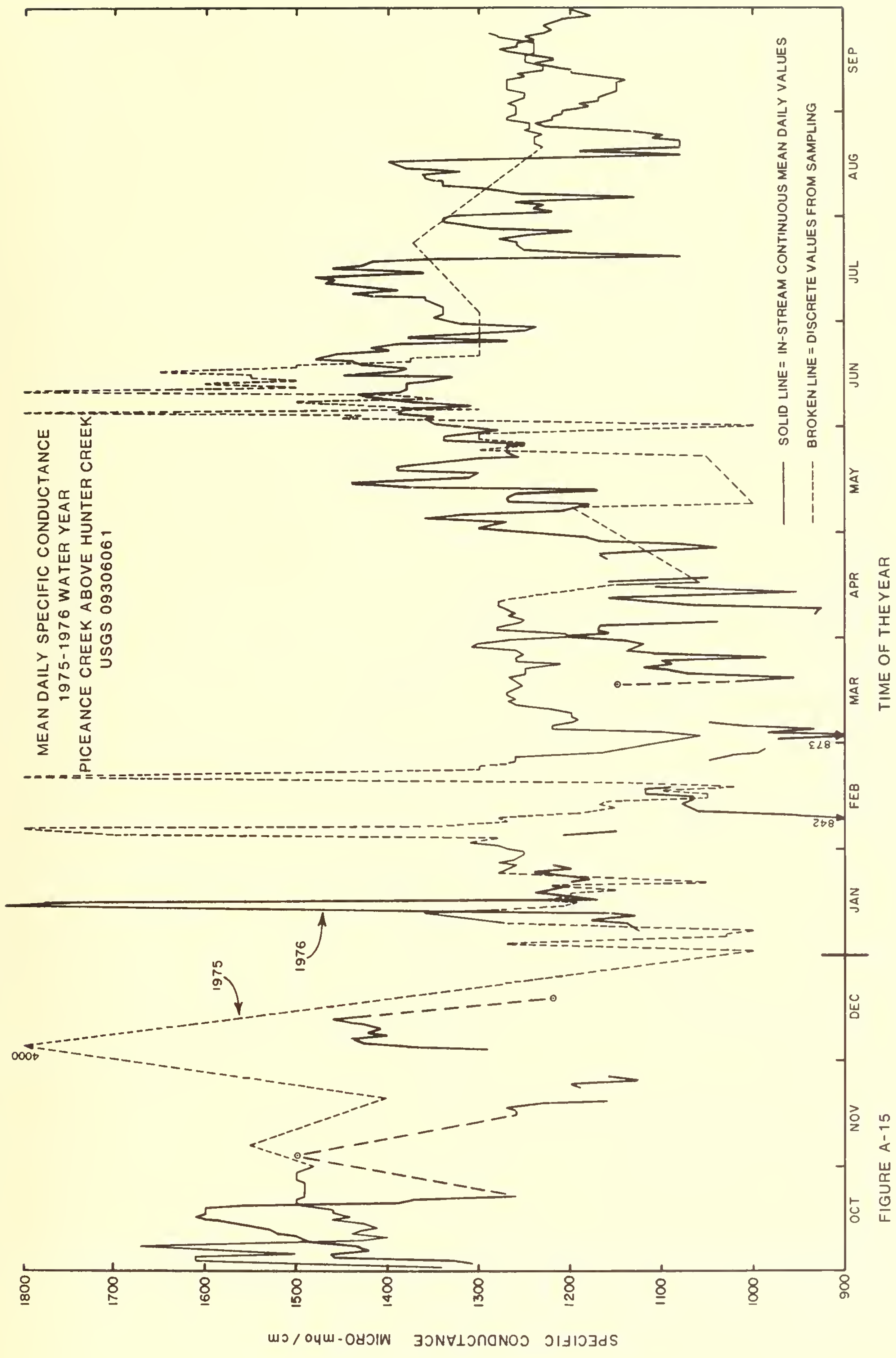
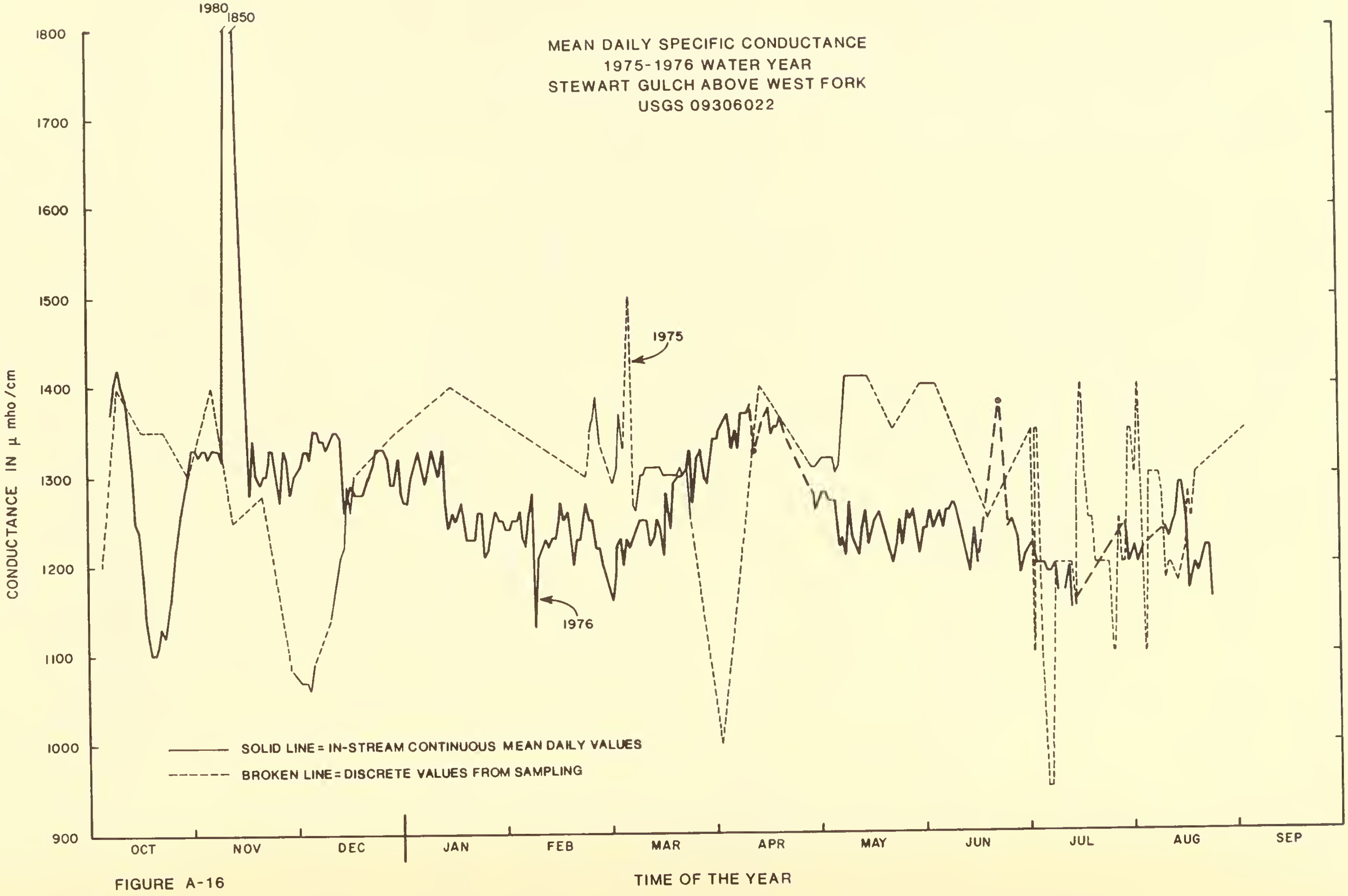

MEAN DAILY SPECIFIC CONDUCTANCE
1975-1976 WATER YEAR
PICEANCE CREEK ABOVE HUNTER CREEK
USGS 09306061
SOLID LINE = IN-STREAM CONTINUOUS MEAN DAILY VALUES
BROKEN LINE = DISCRETE VALUES FROM SAMPLING
1975
1976
4000
842
873
SPECIFIC CONDUCTANCE MICRO-mho / cm
1800
1700
1600
1500
1400
1300
1200
1100
1000
900
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
TIME OF THE YEAR

FIGURE A-15



MEAN DAILY SPECIFIC CONDUCTANCE
1975-1976 WATER YEAR
STEWART GULCH ABOVE WEST FORK
USGS 09306022

FIGURE A-16

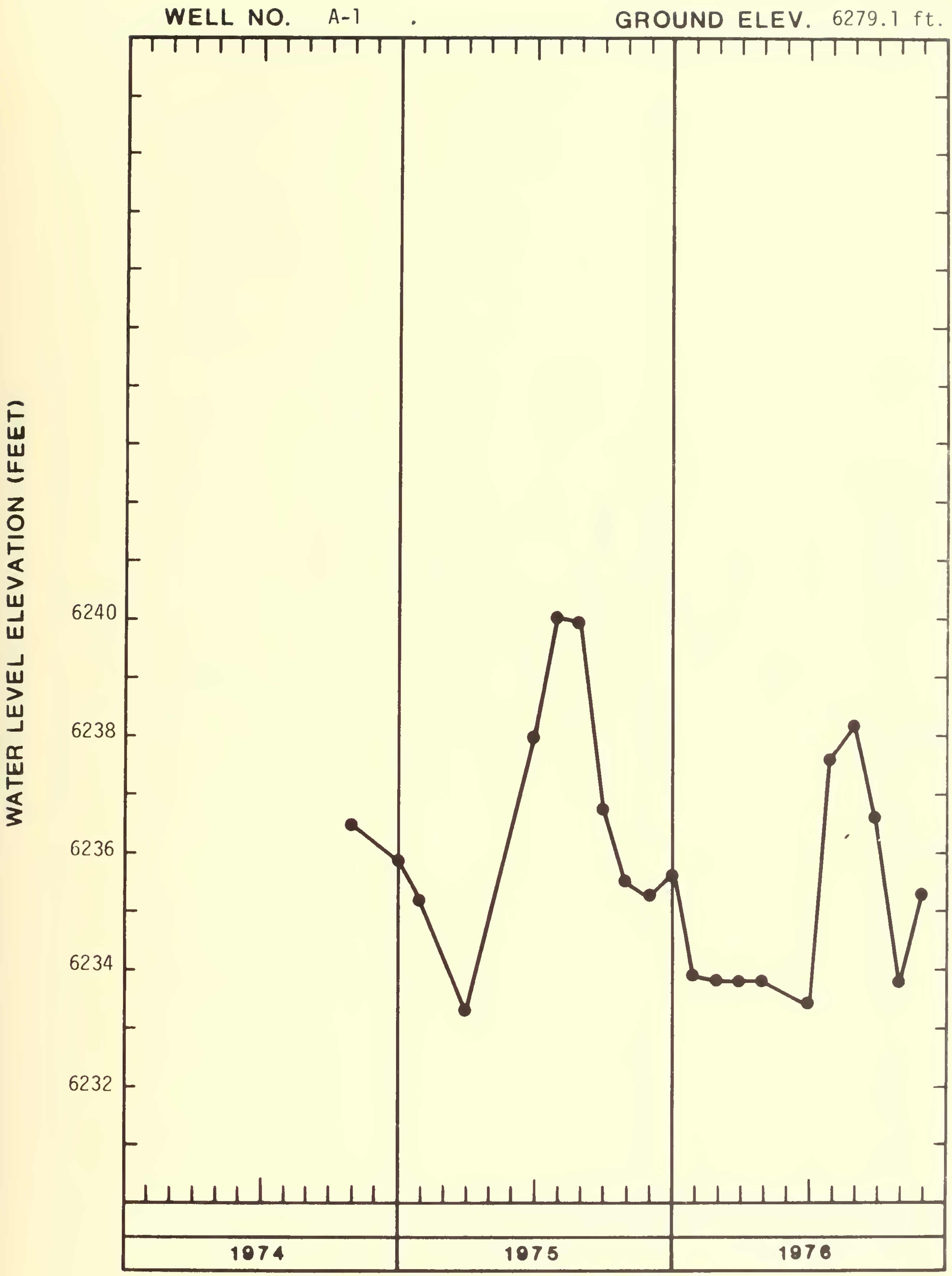


FIGURE A-17 WATER LEVEL DATA

WELL NO. A-2 **GROUND ELEV.** 6281.4 ft.

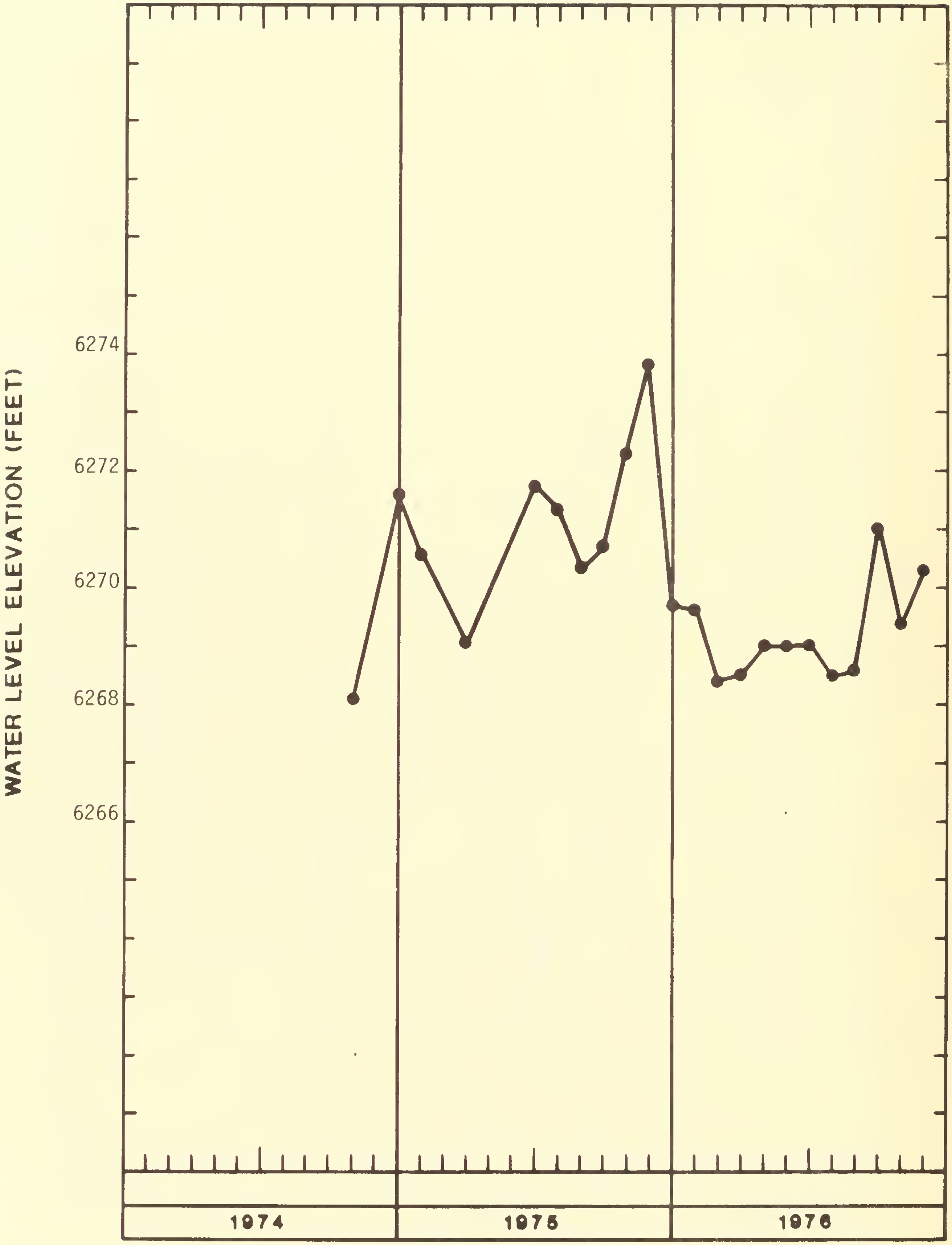


FIGURE A-18 WATER LEVEL DATA

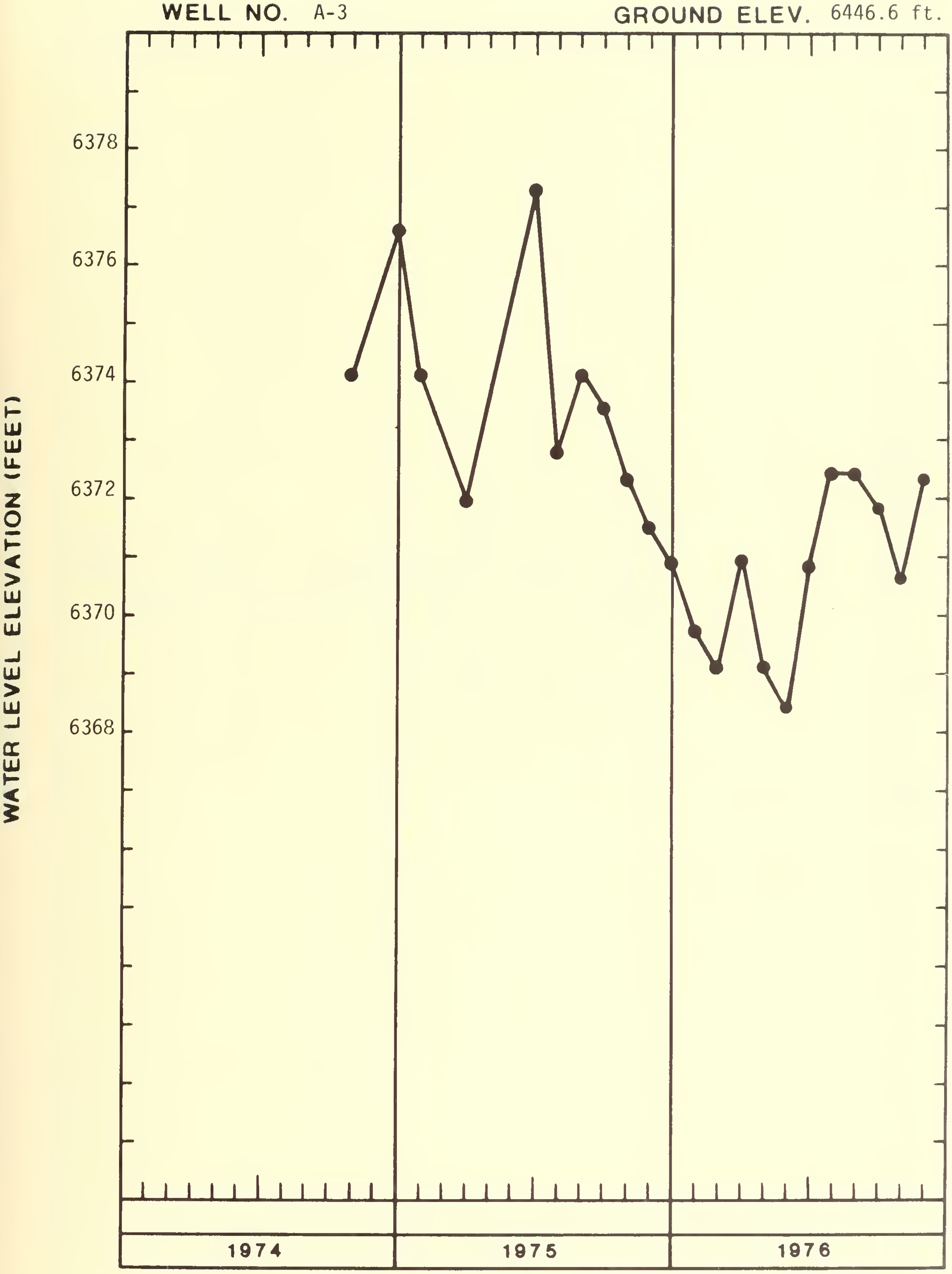


FIGURE A-19 WATER LEVEL DATA

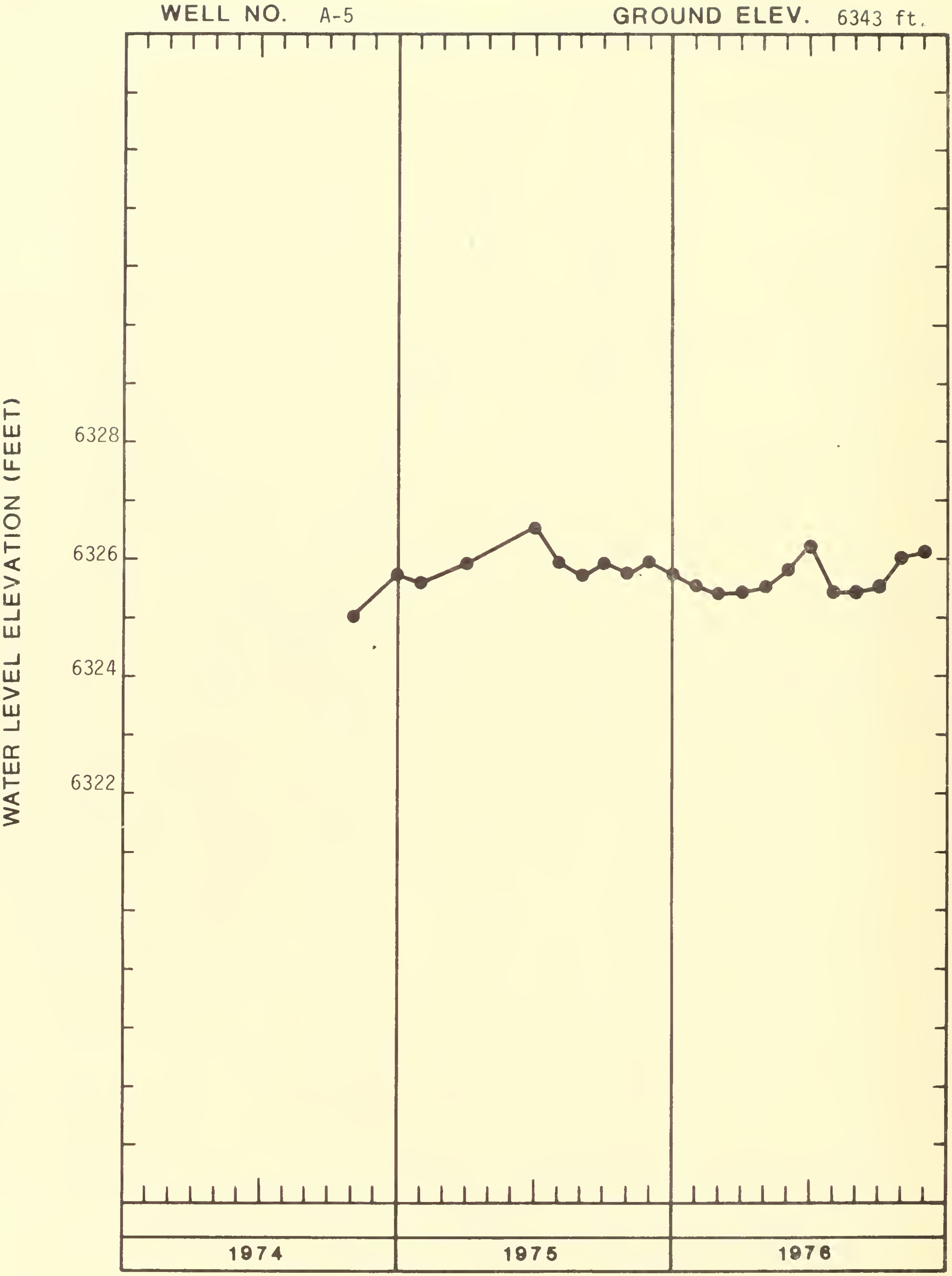


FIGURE A-20 WATER LEVEL DATA

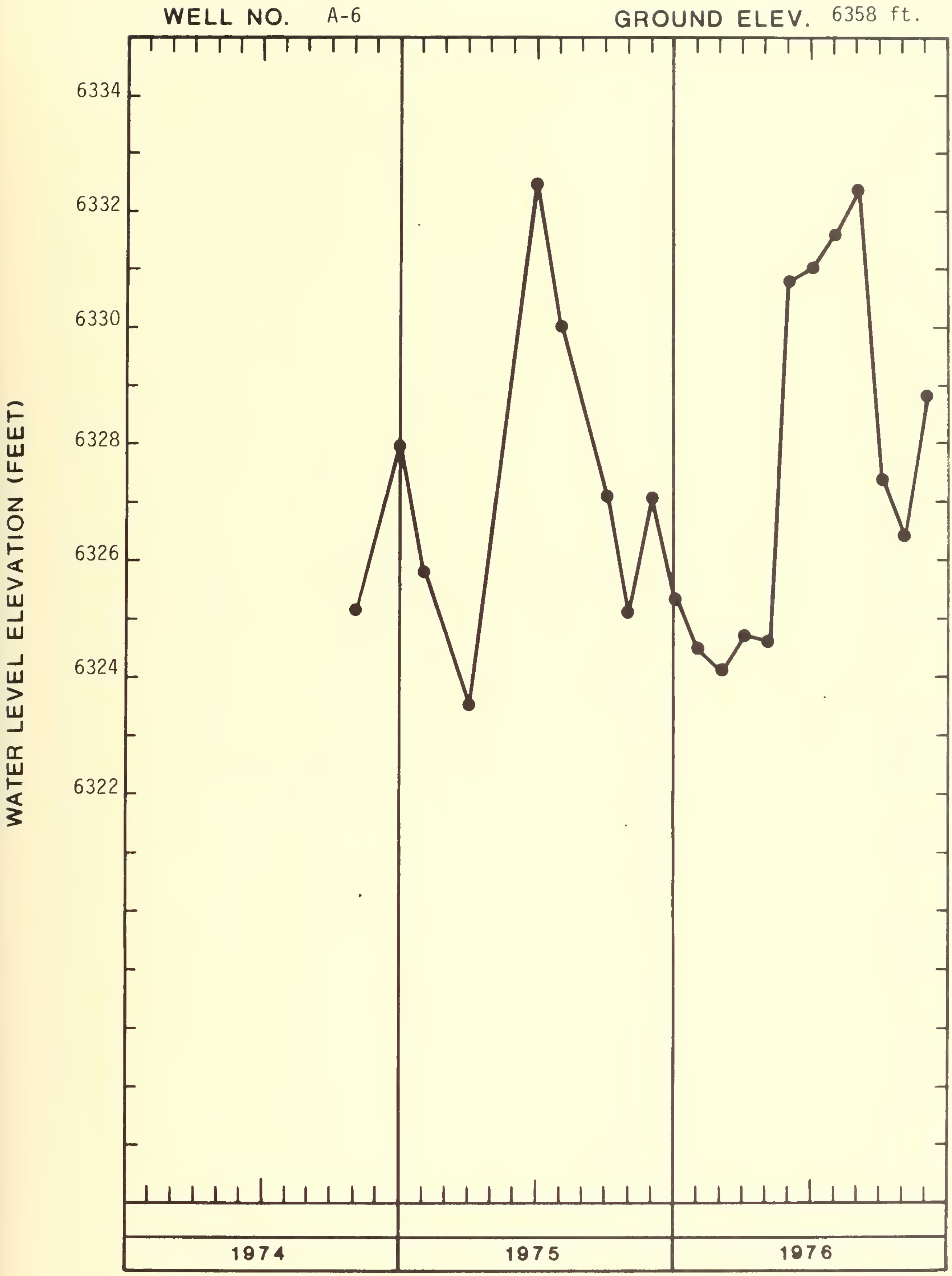


FIGURE A-21 WATER LEVEL DATA

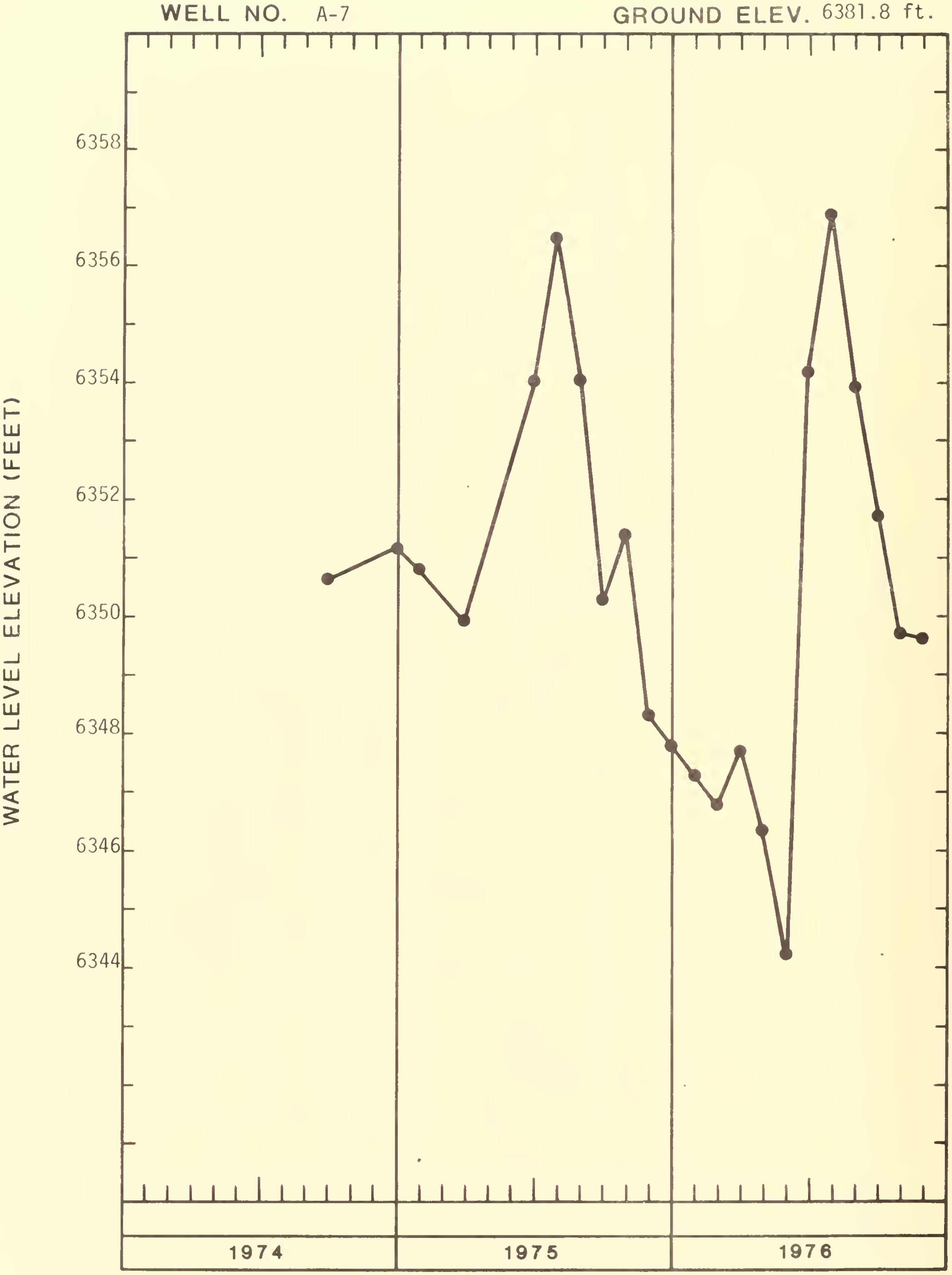


FIGURE A-22 WATER LEVEL DATA

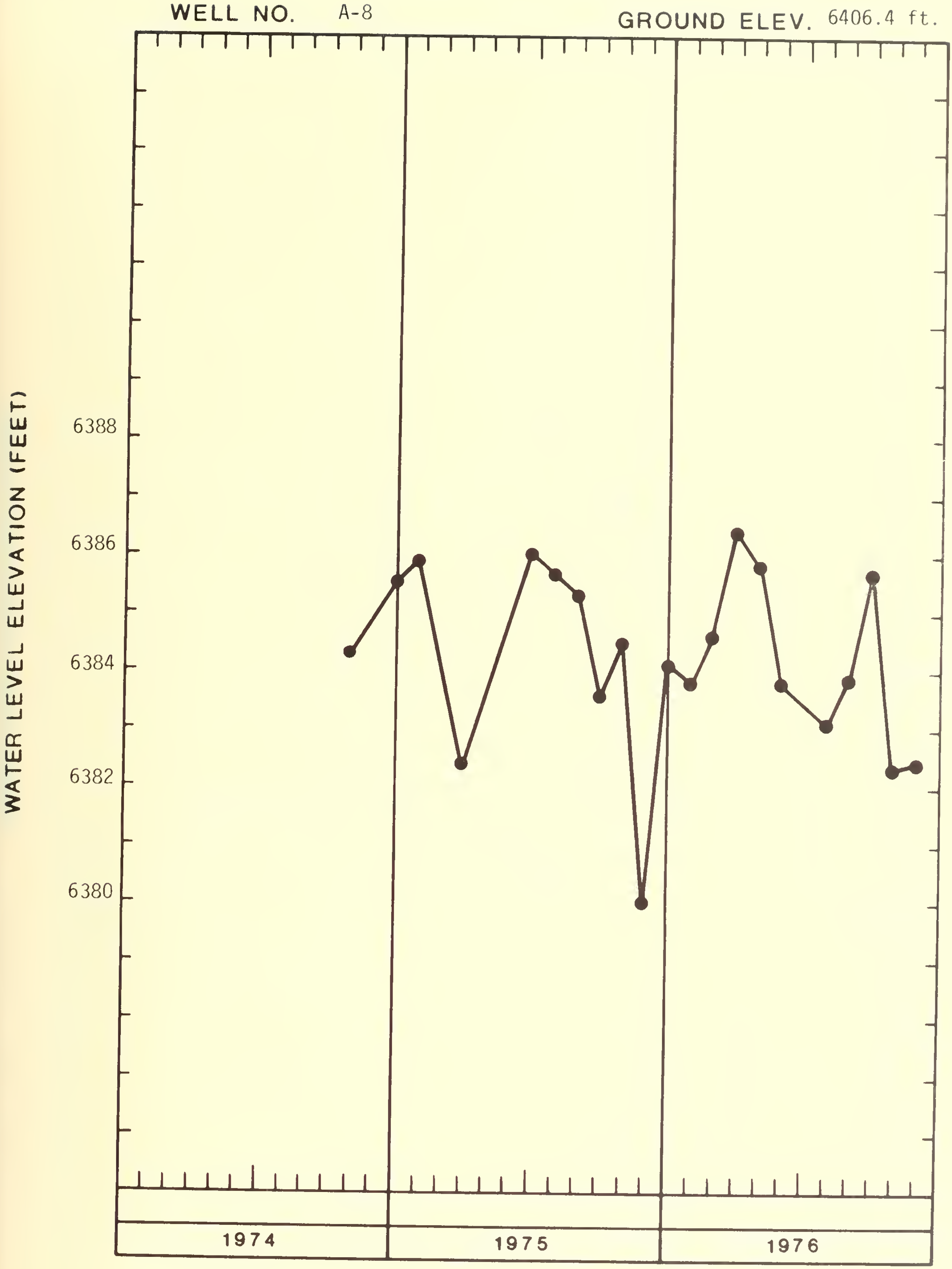


FIGURE A-23 WATER LEVEL DATA

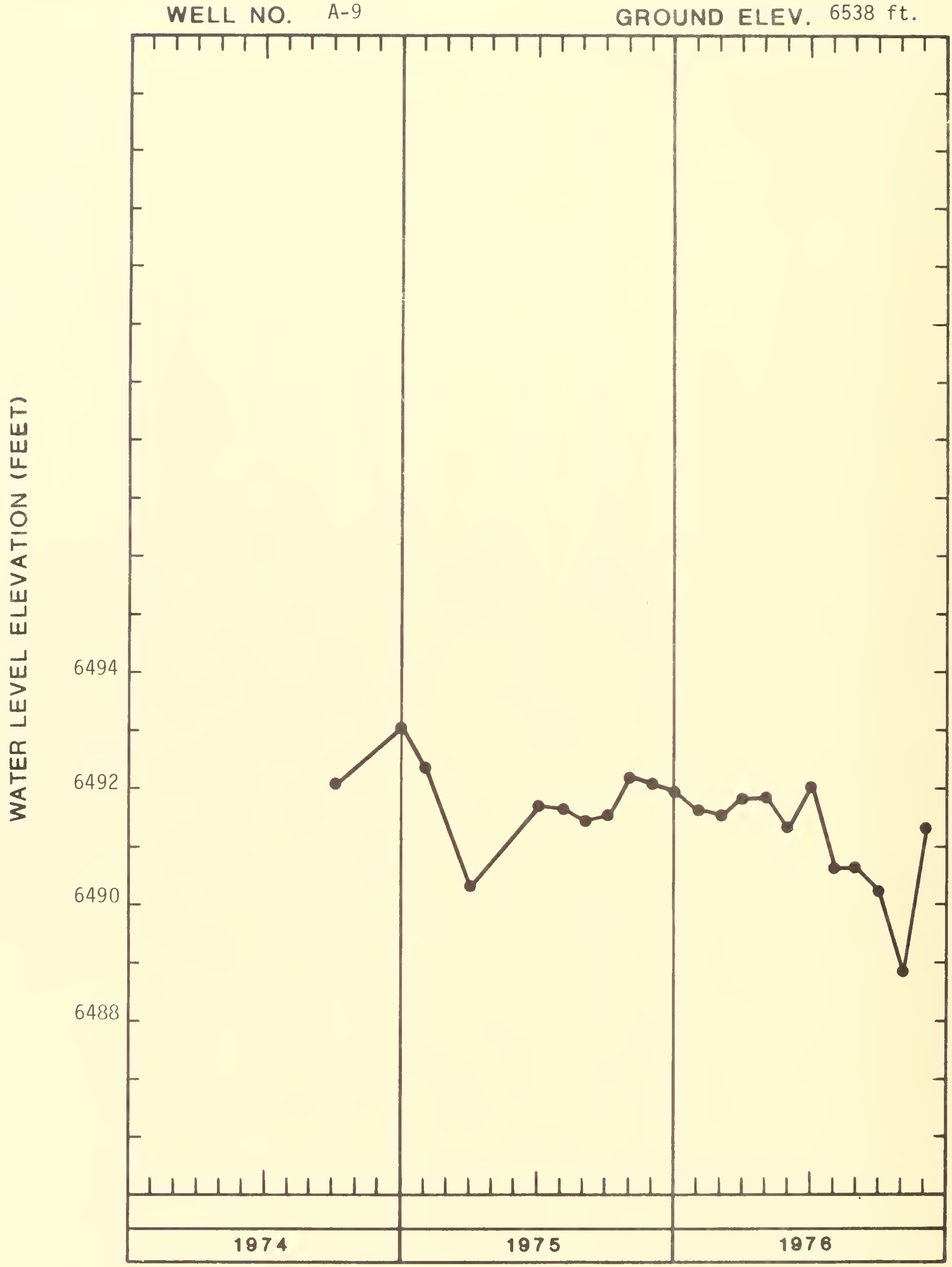


FIGURE A-24 WATER LEVEL DATA

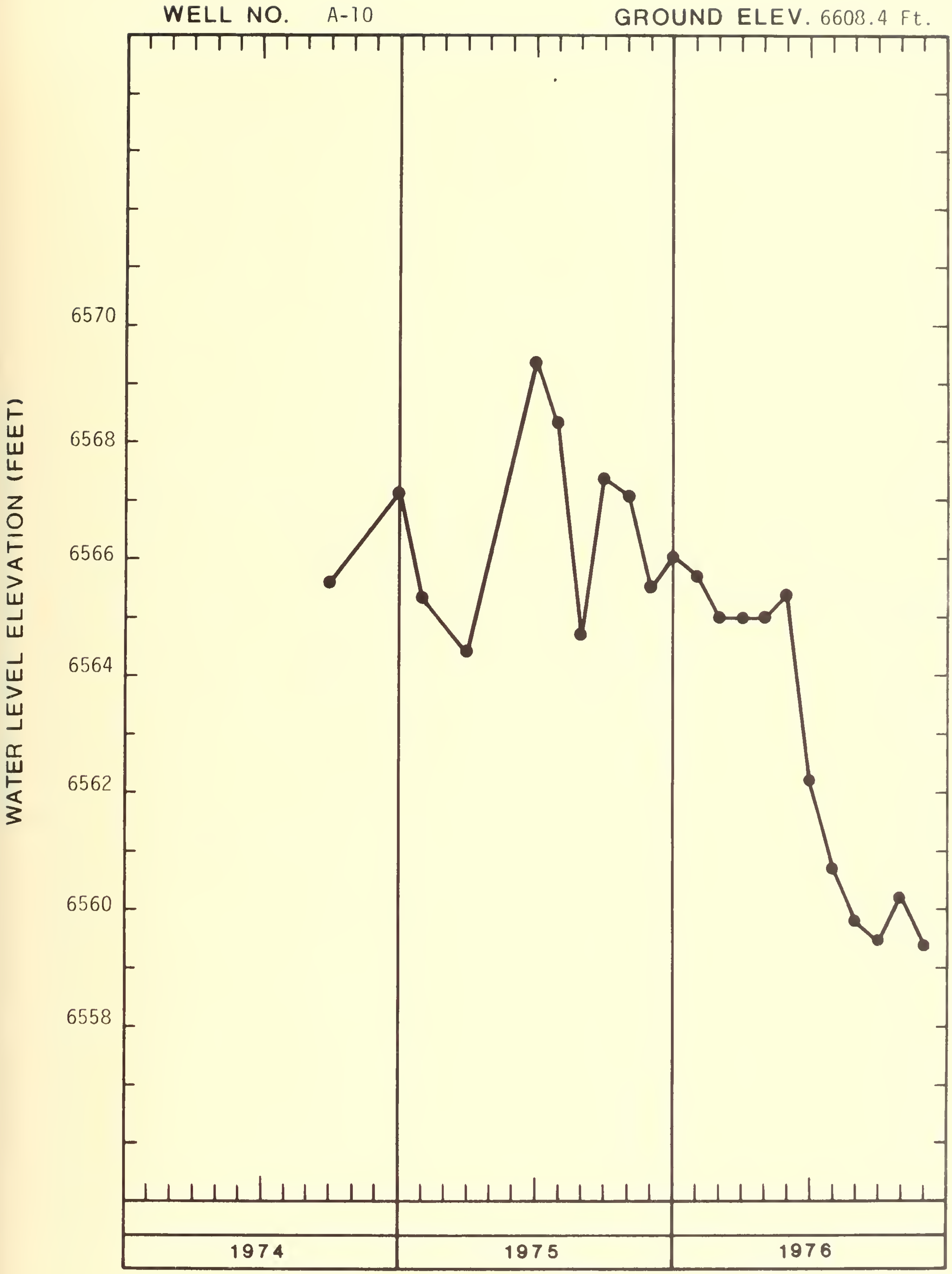


FIGURE A-25 WATER LEVEL DATA

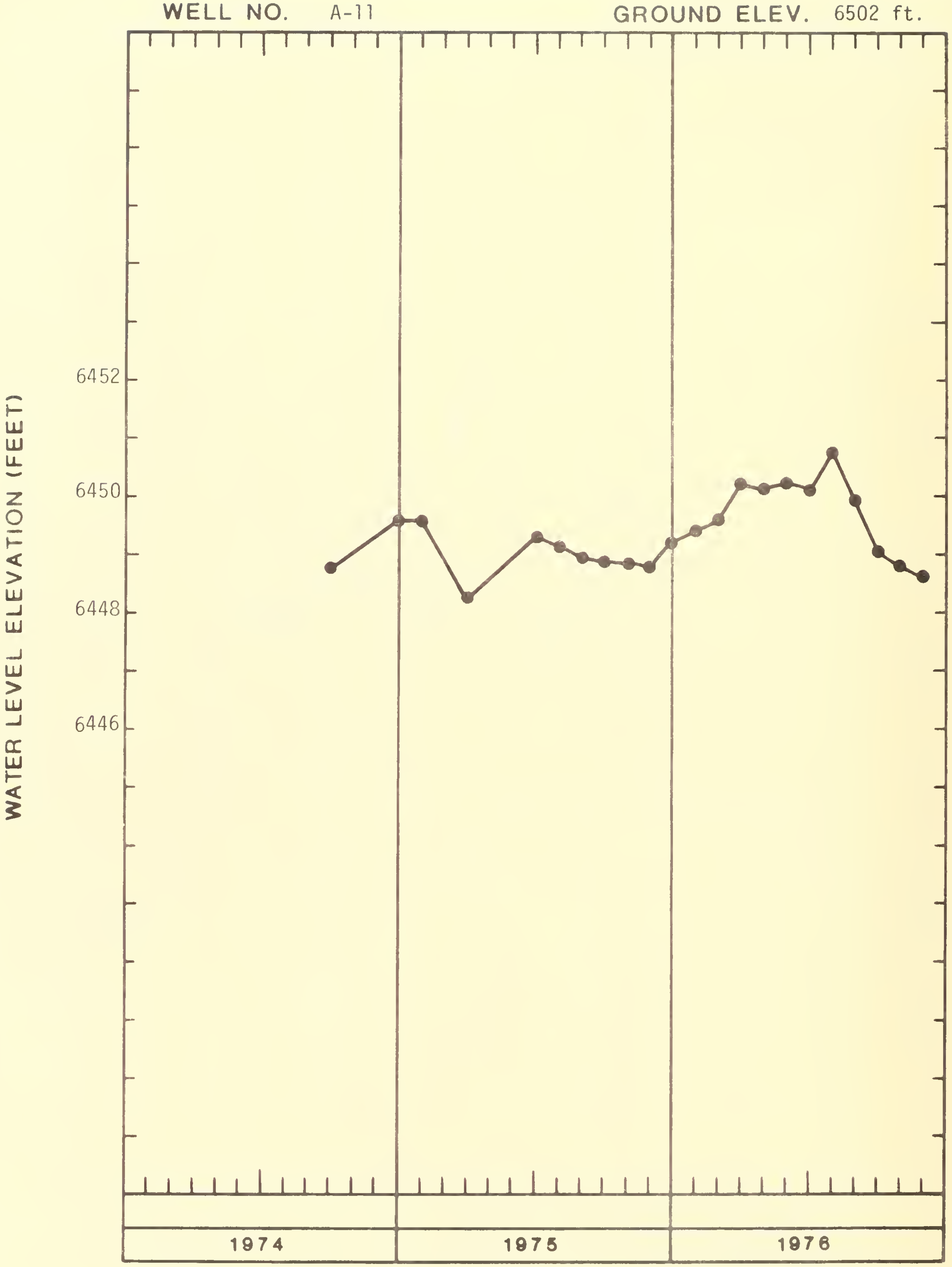


FIGURE A-26 WATER LEVEL DATA

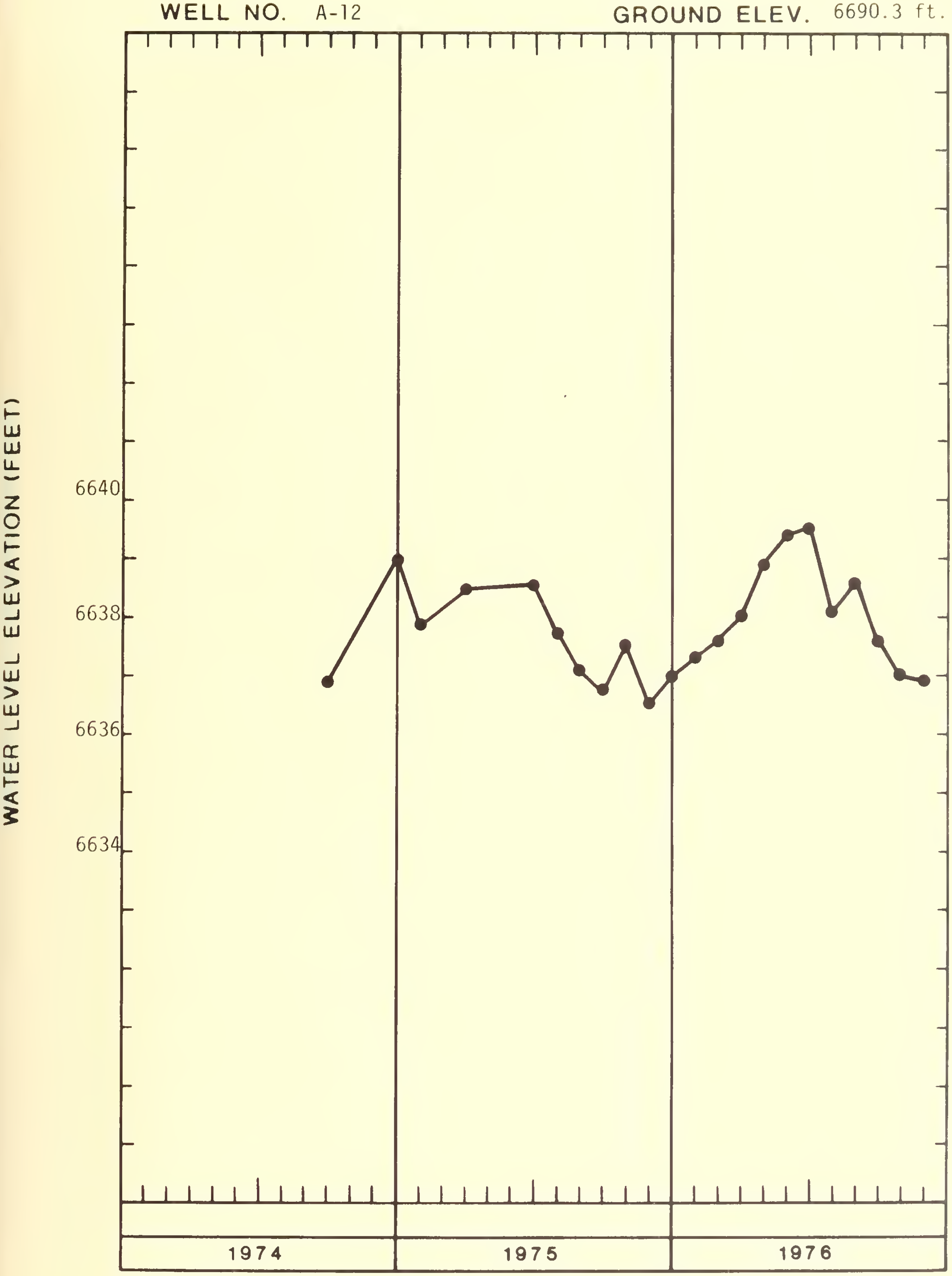


FIGURE A-27 WATER LEVEL DATA

WELL NO. Cb-2 GROUND ELEV. 6737 ft.

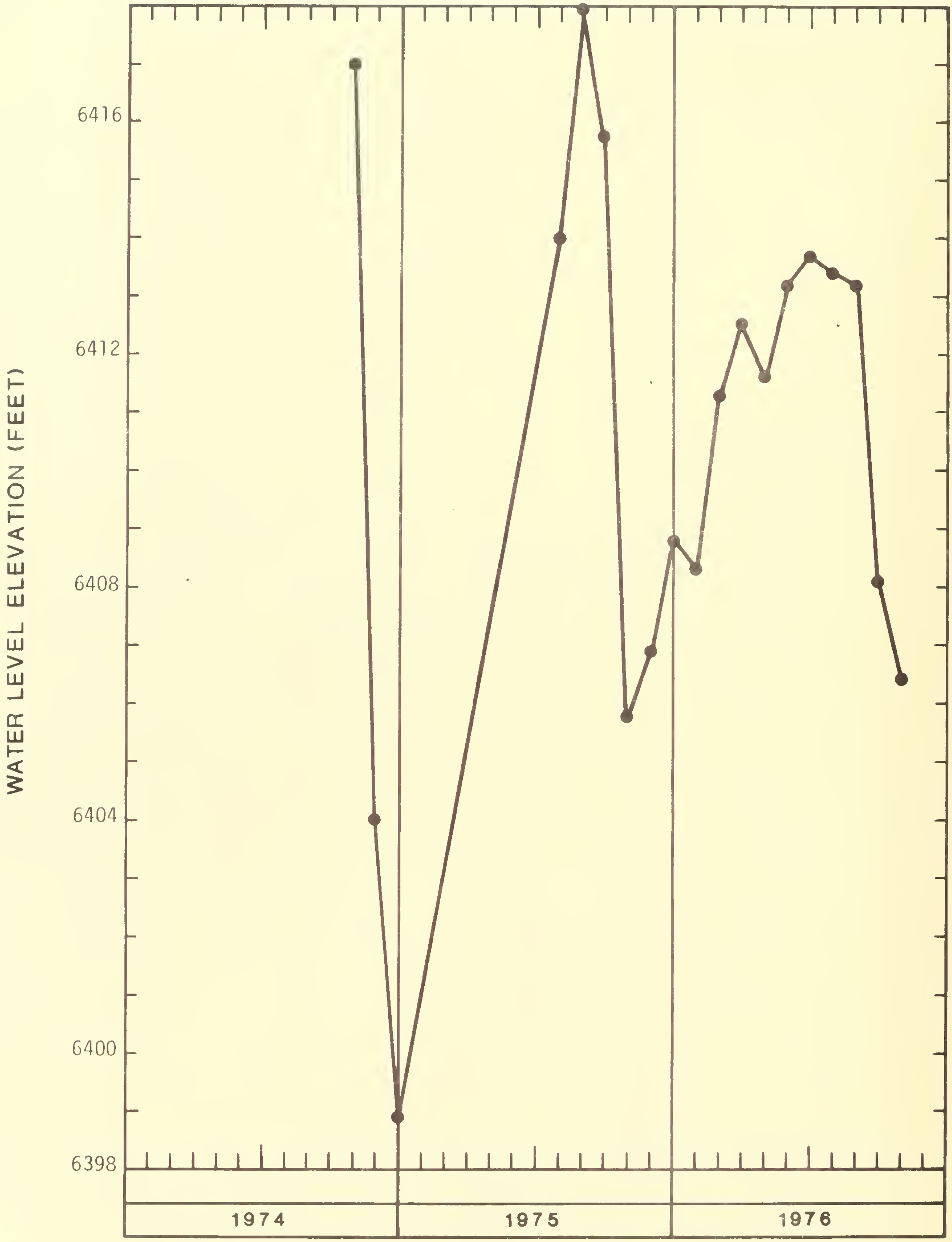


FIGURE A-28 WATER LEVEL DATA

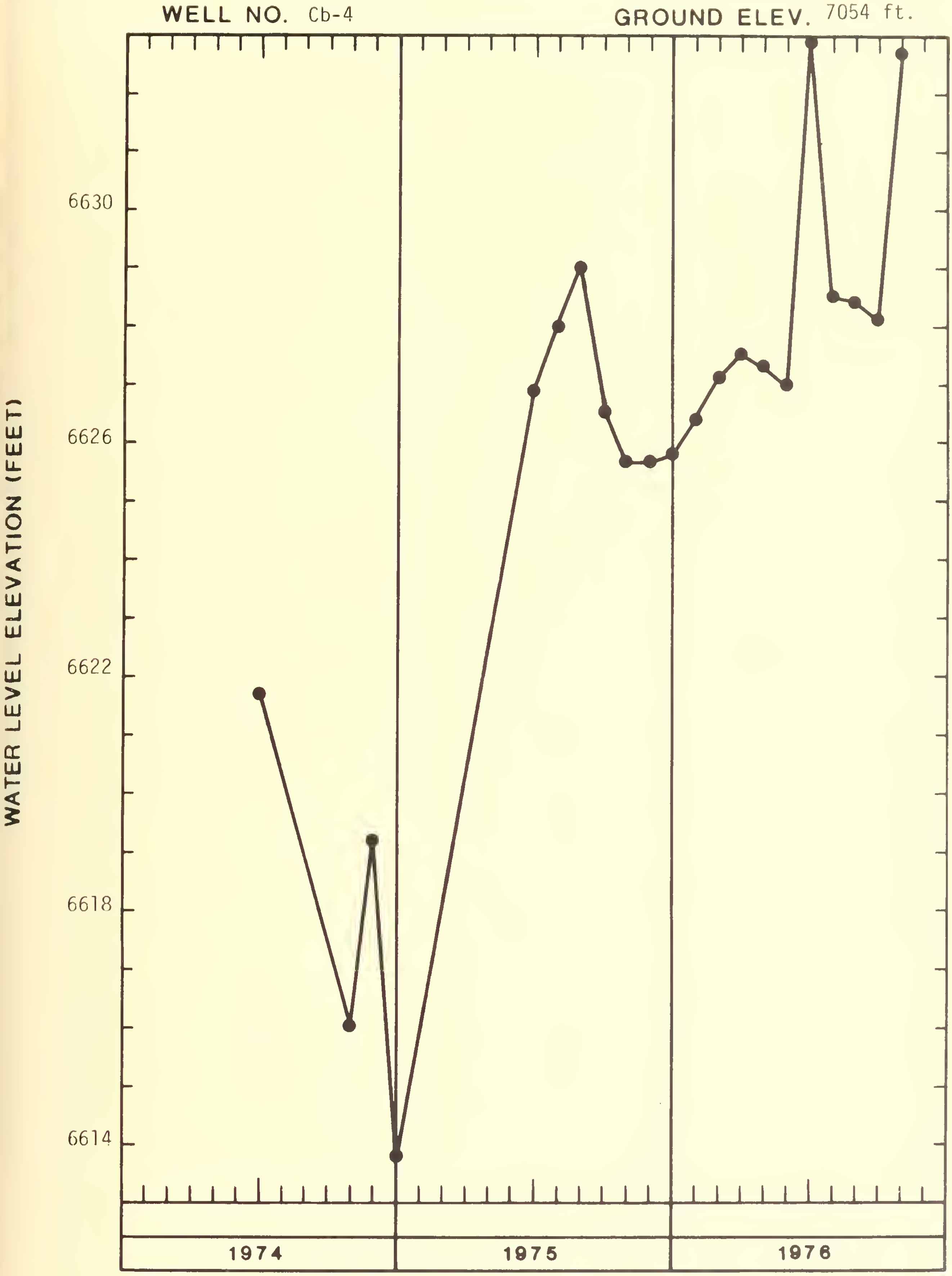


FIGURE A-29 WATER LEVEL DATA

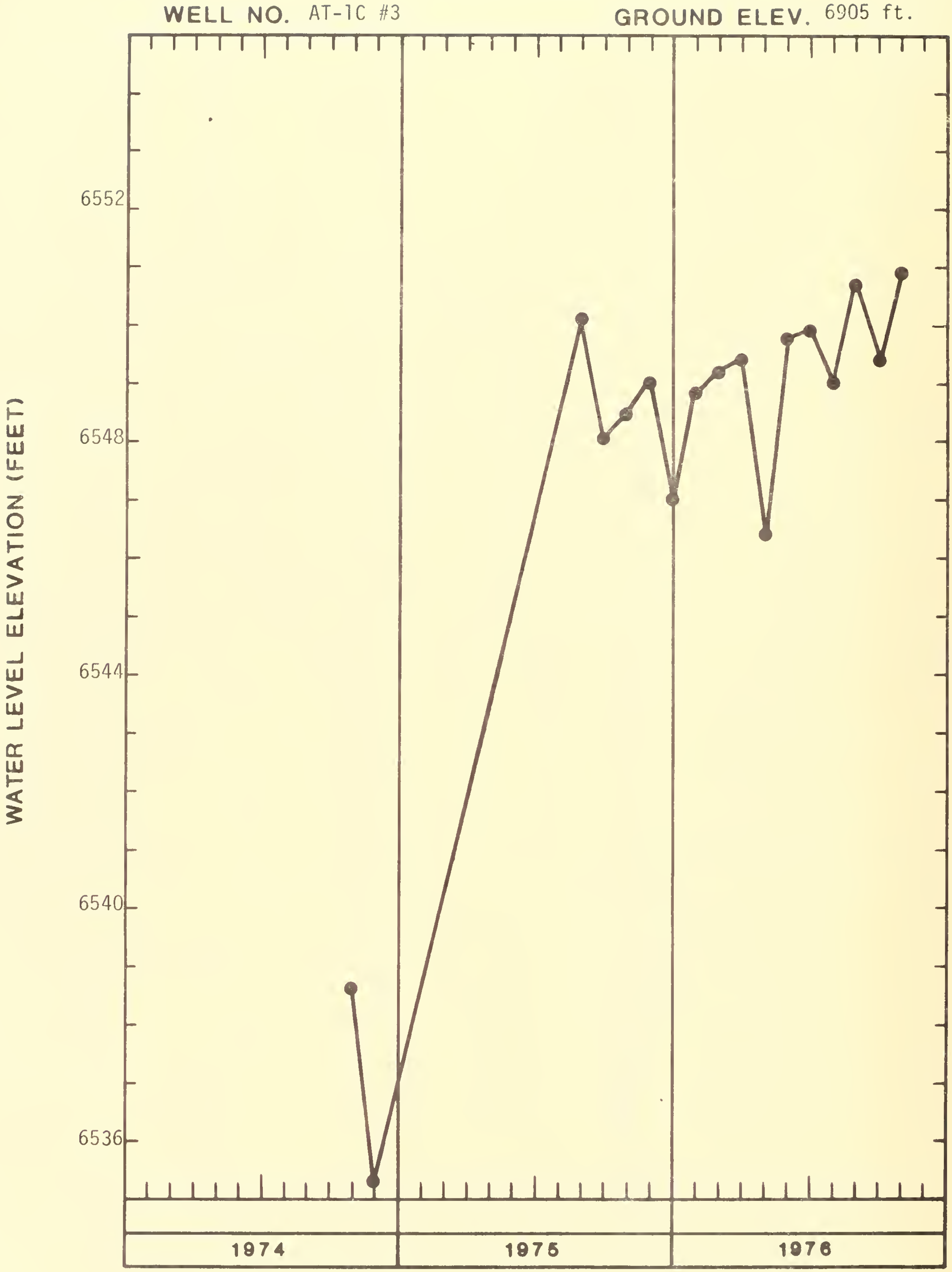


FIGURE A-30 WATER LEVEL DATA

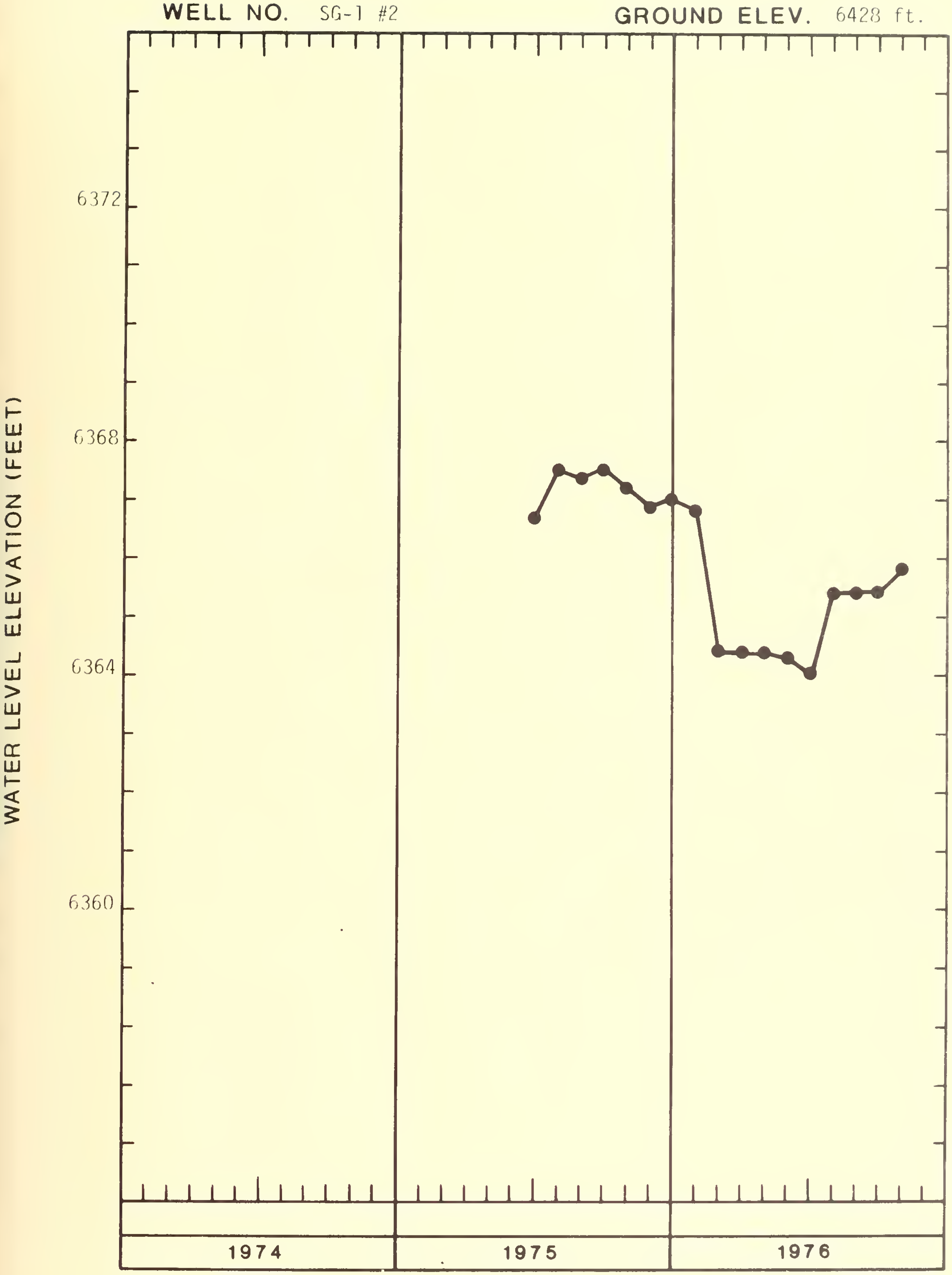


FIGURE A-31 WATER LEVEL DATA

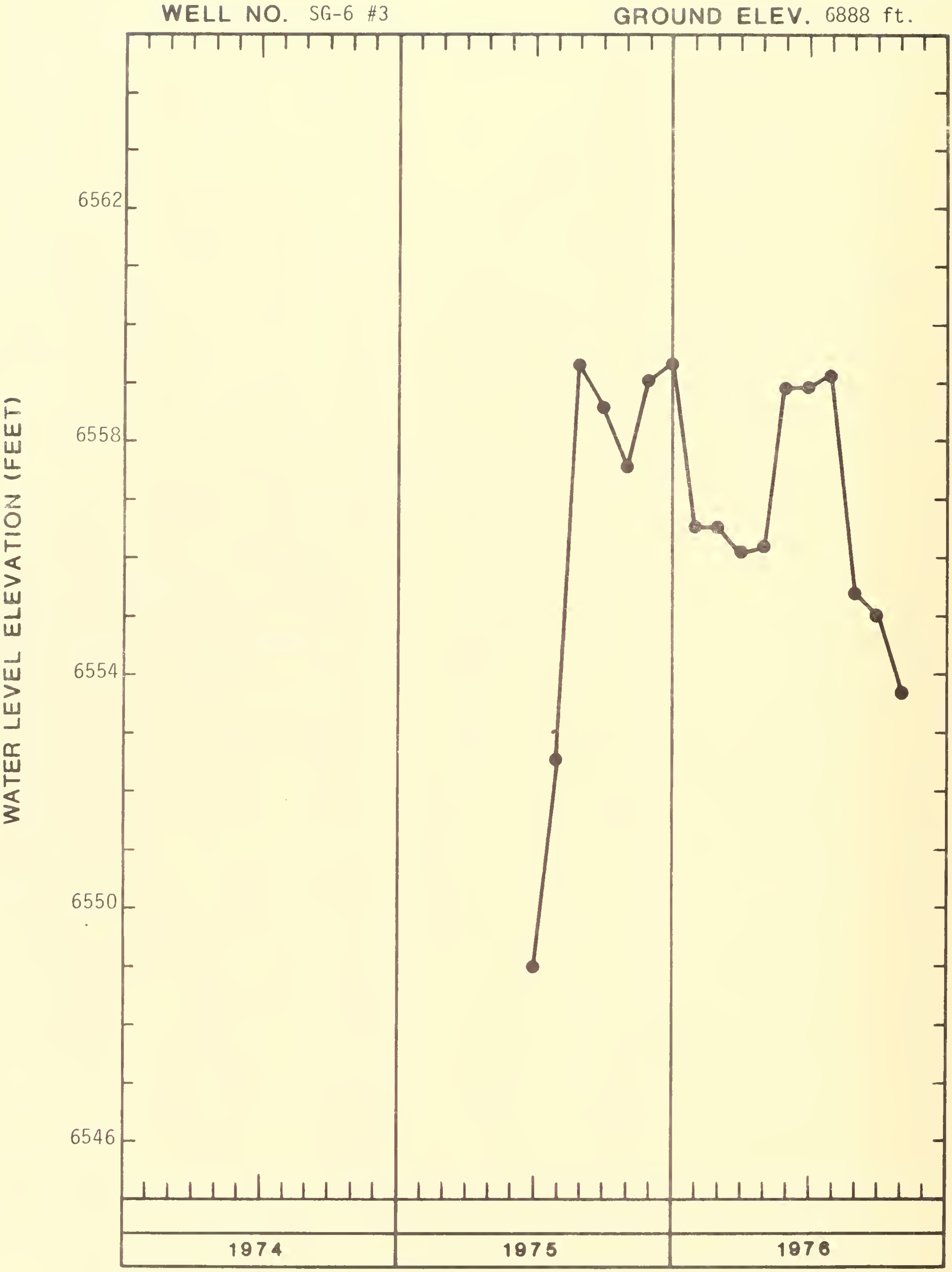


FIGURE A-32 WATER LEVEL DATA

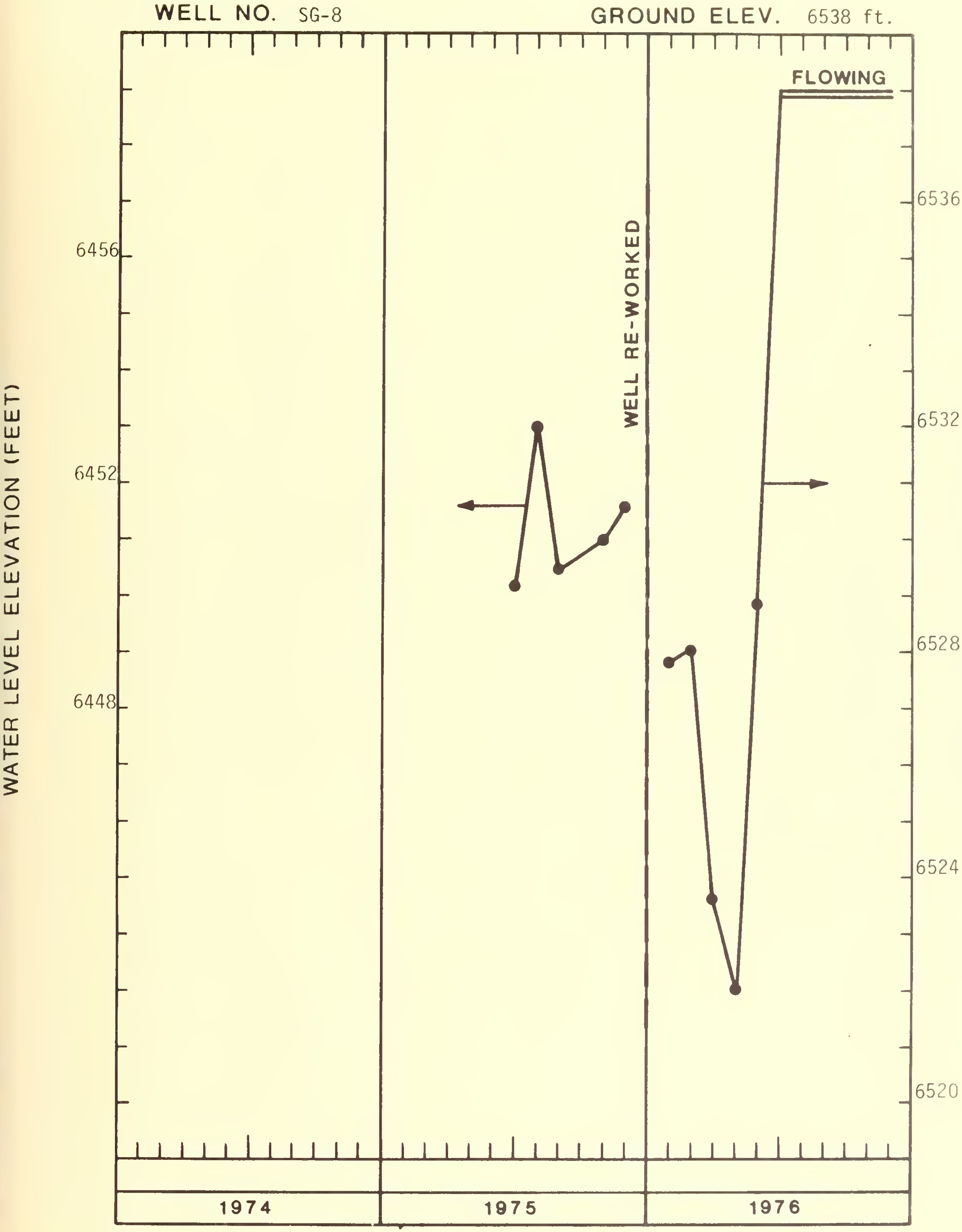


FIGURE A-33 WATER LEVEL DATA

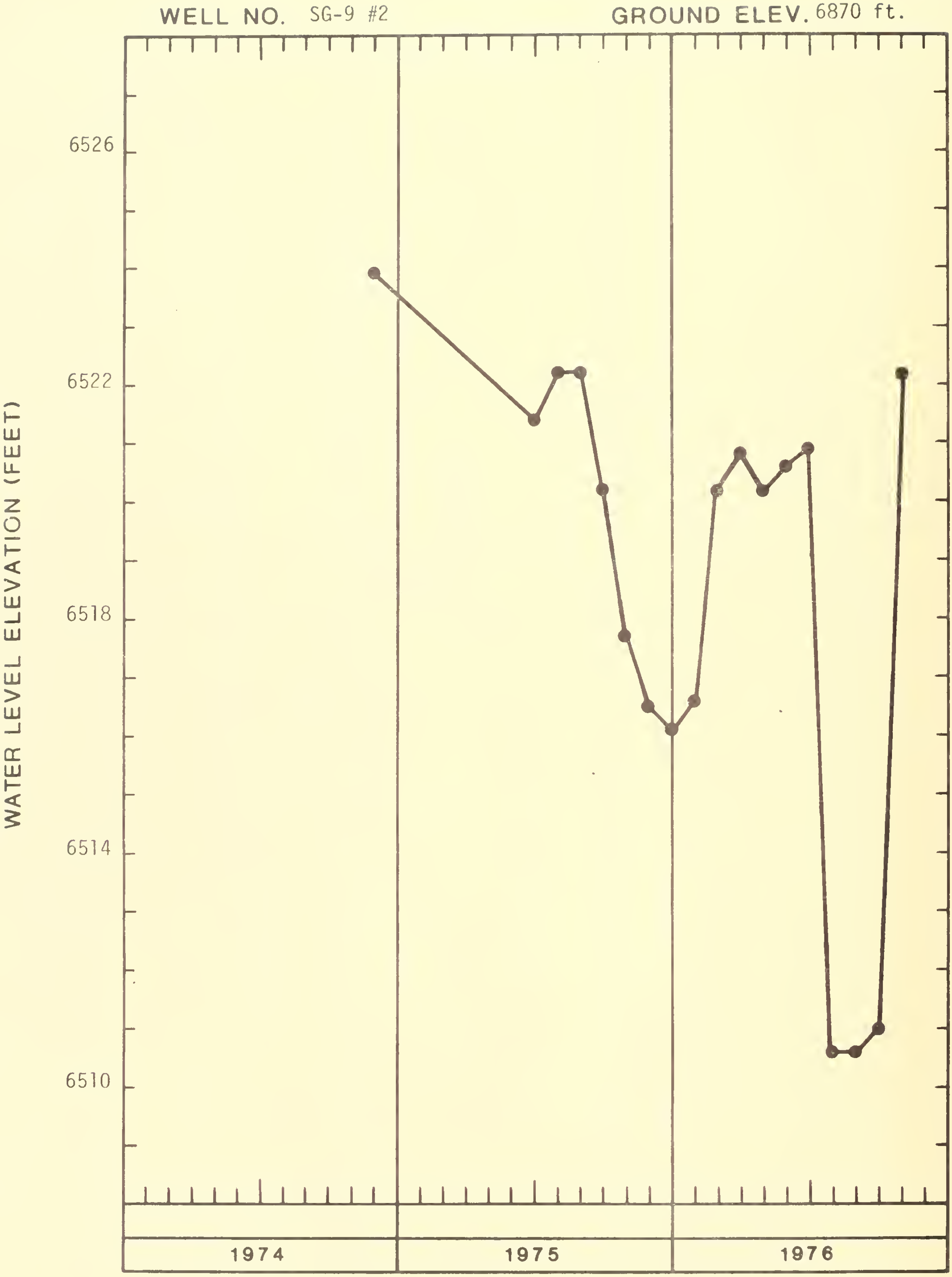


FIGURE A-34 WATER LEVEL DATA

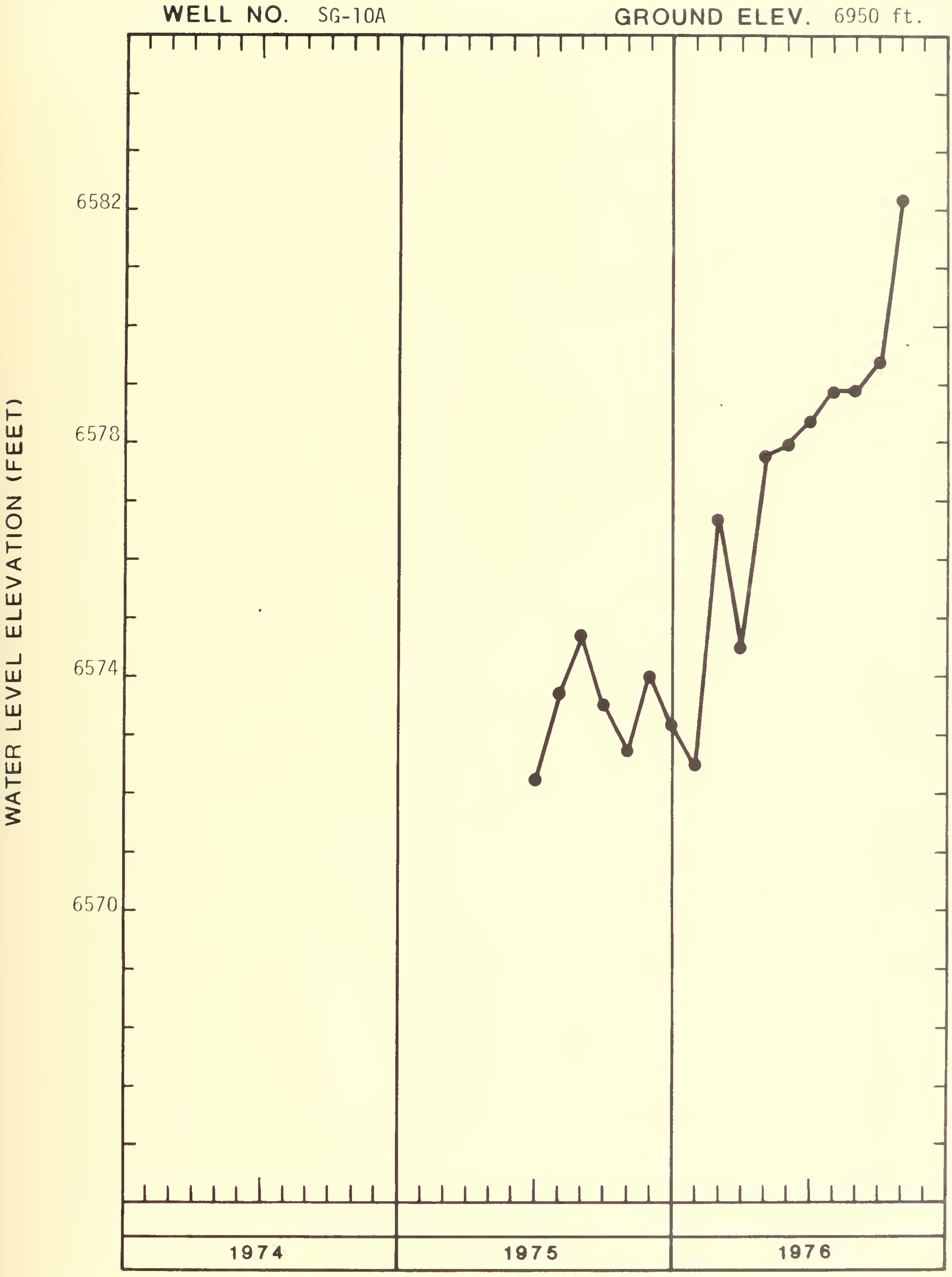


FIGURE A-35 WATER LEVEL DATA

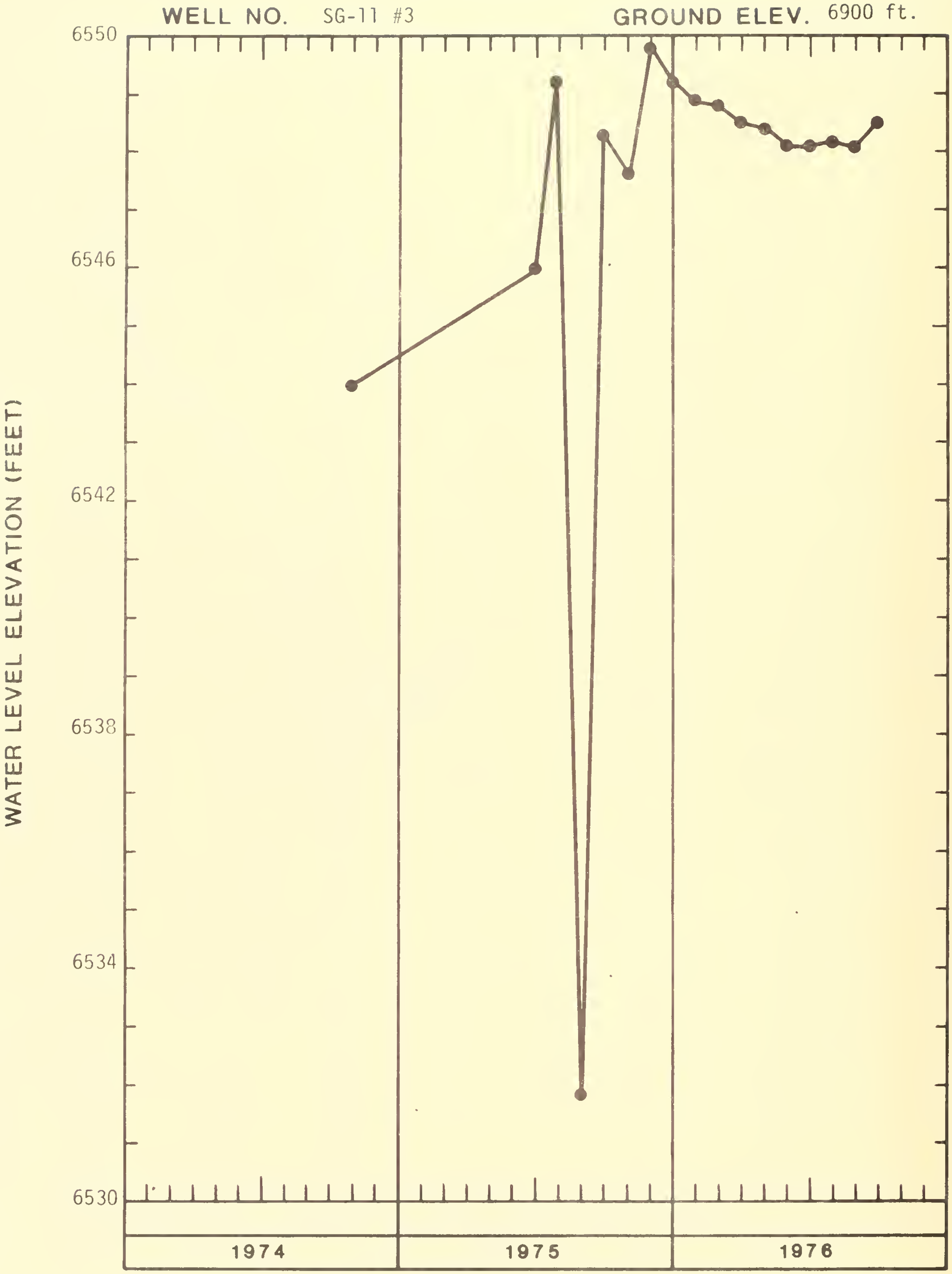


FIGURE A-36 WATER LEVEL DATA

FIGURE A-37 WATER LEVEL DATA

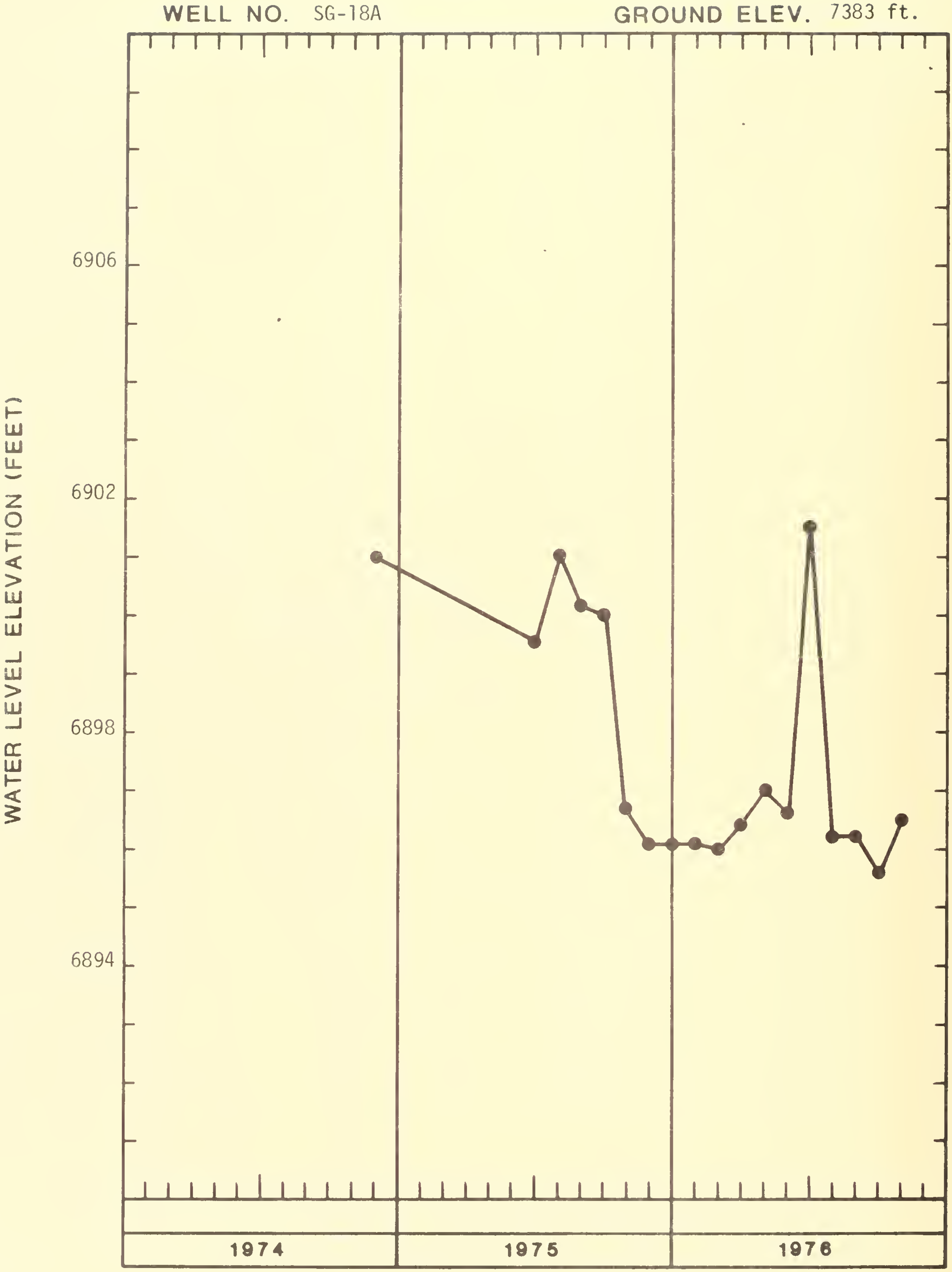


FIGURE A-38 WATER LEVEL DATA

FIGURE A-39 WATER LEVEL DATA

FIGURE A-40 WATER LEVEL DATA

WELL NO. AT-1C #1 **GROUND ELEV.** 6905 ft.

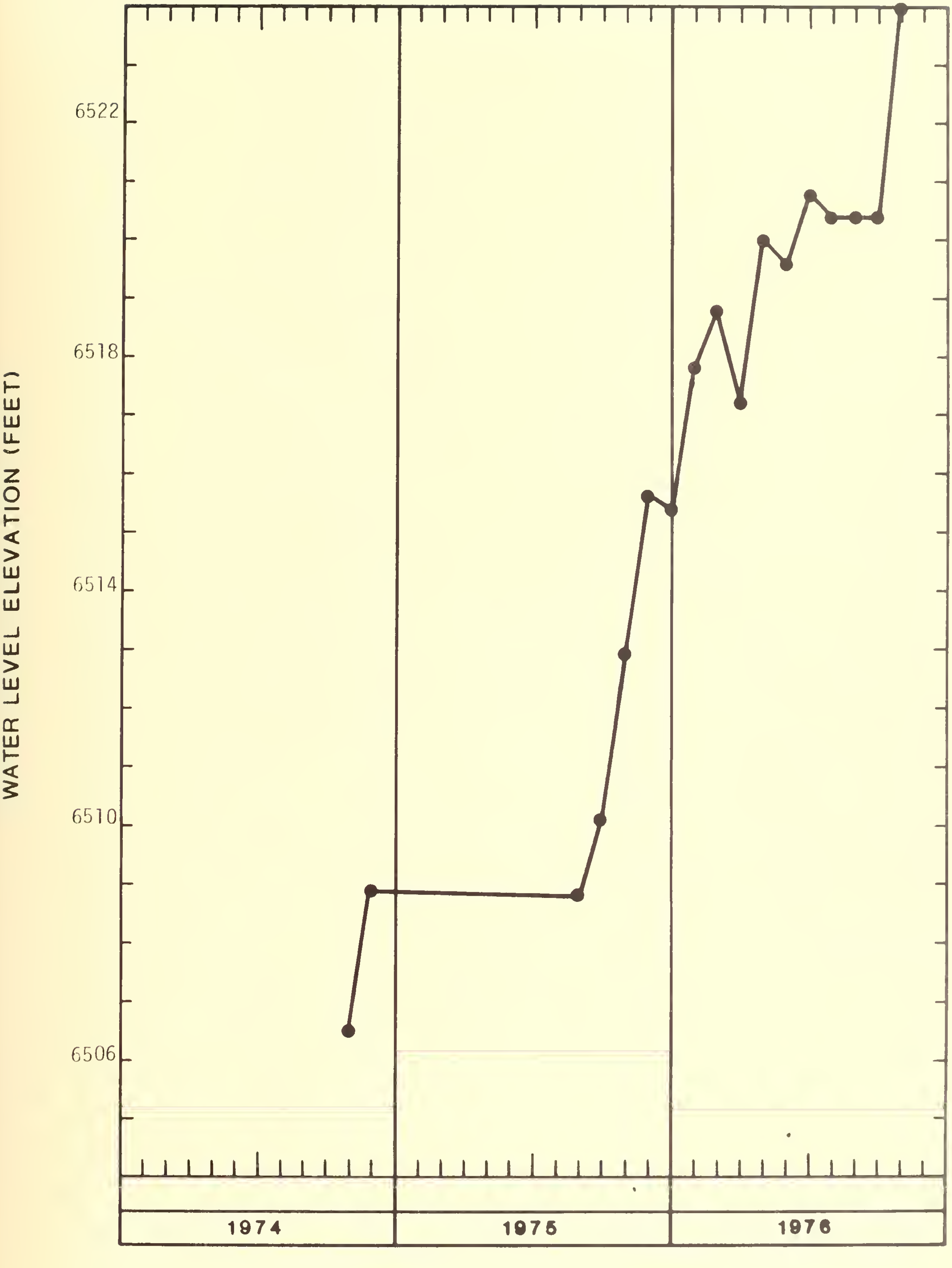


FIGURE A-41 WATER LEVEL DATA

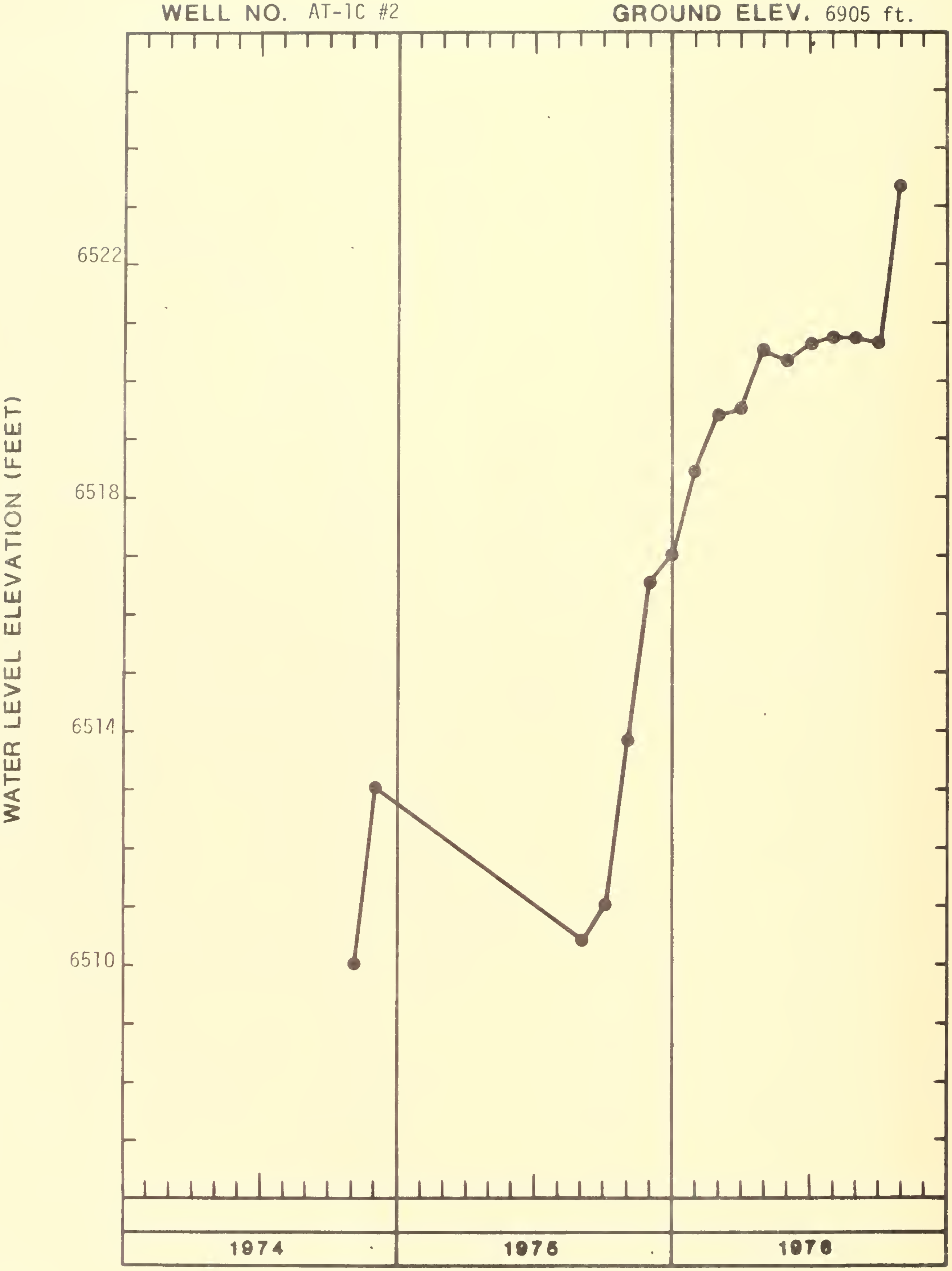


FIGURE A-42 WATER LEVEL DATA

FIGURE A-43 WATER LEVEL DATA

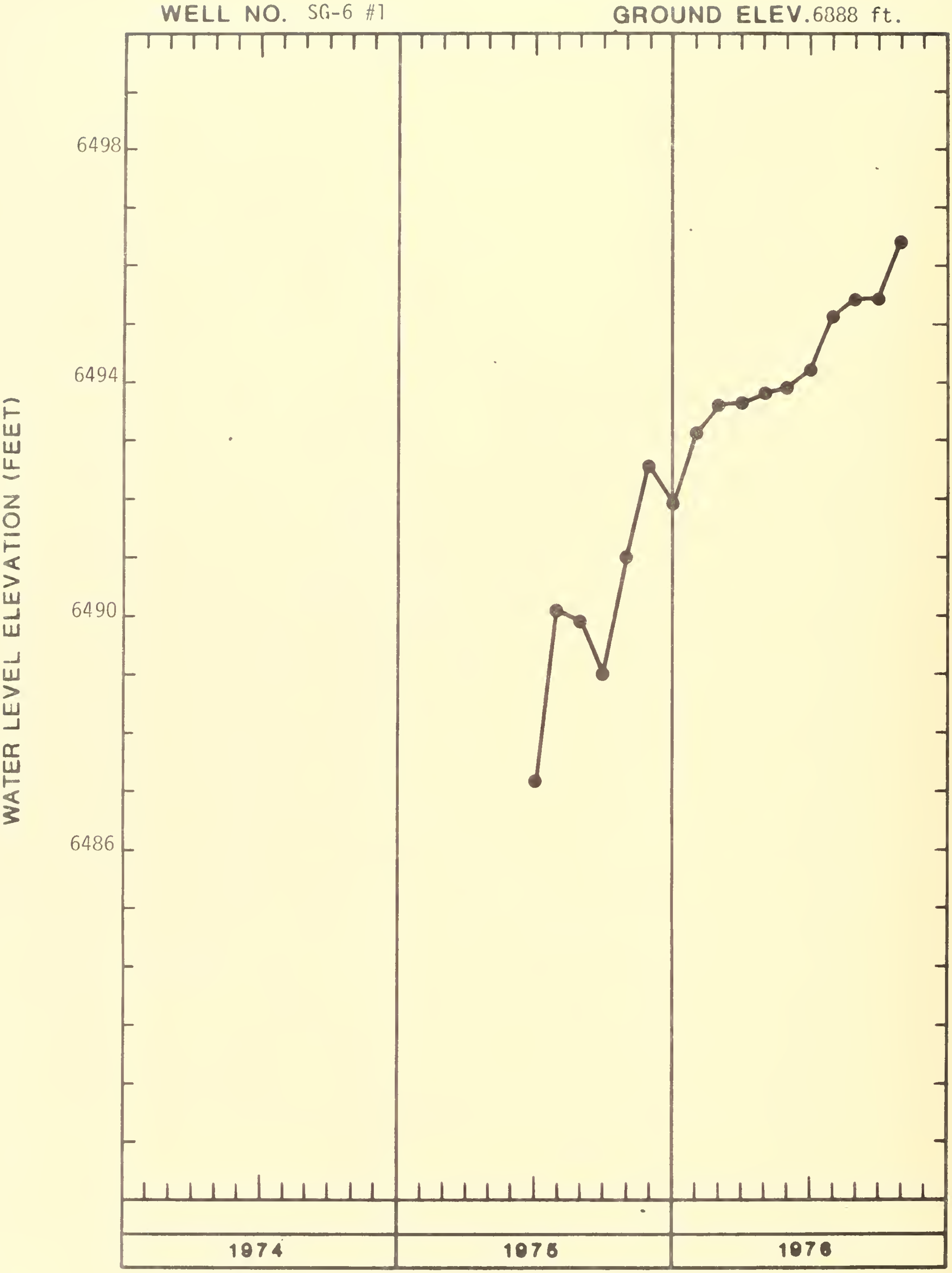


FIGURE A-44 WATER LEVEL DATA

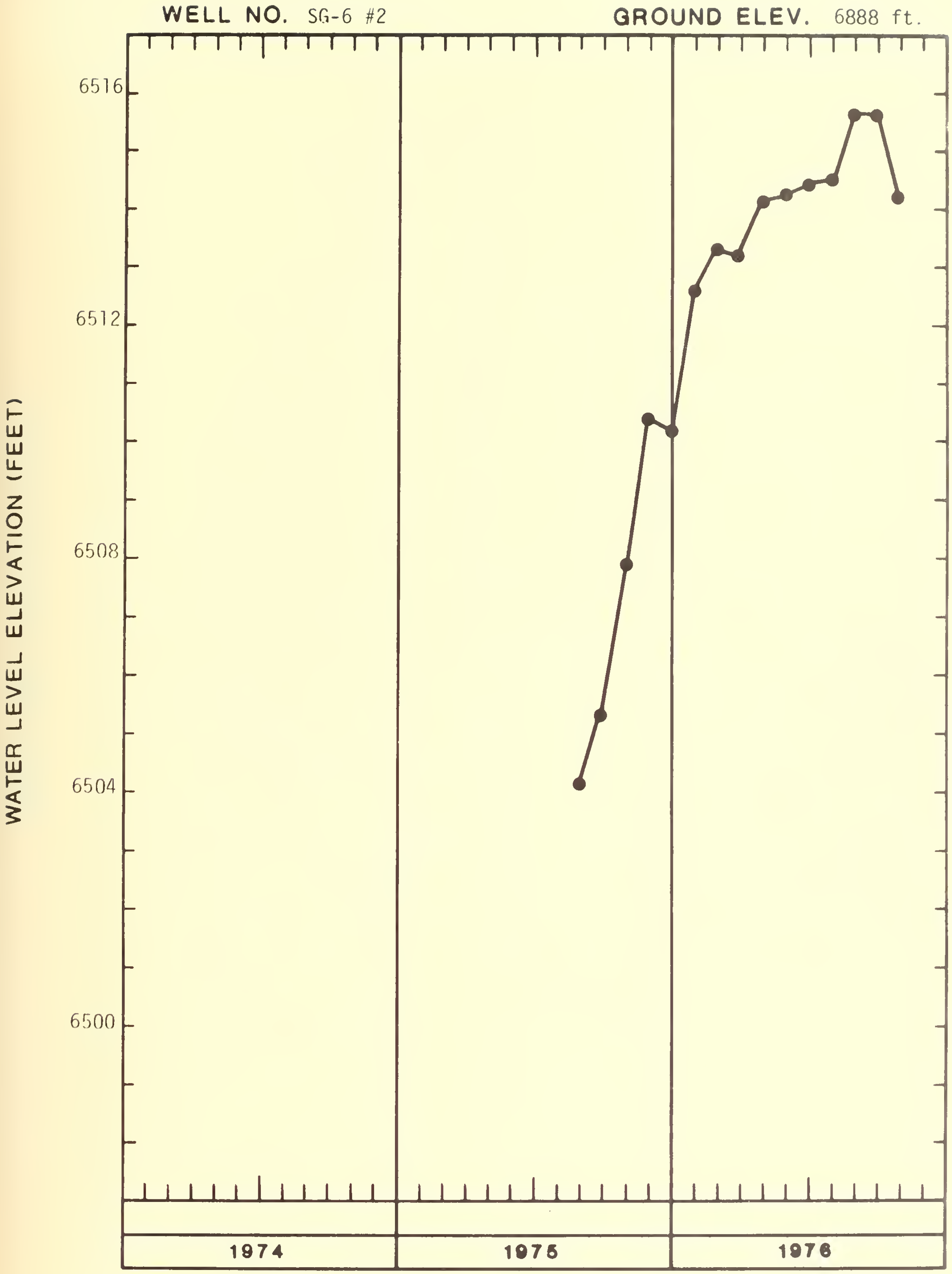


FIGURE A-45 WATER LEVEL DATA

WELL NO. SG-9 #1 **GROUND ELEV.** 6870 ft.

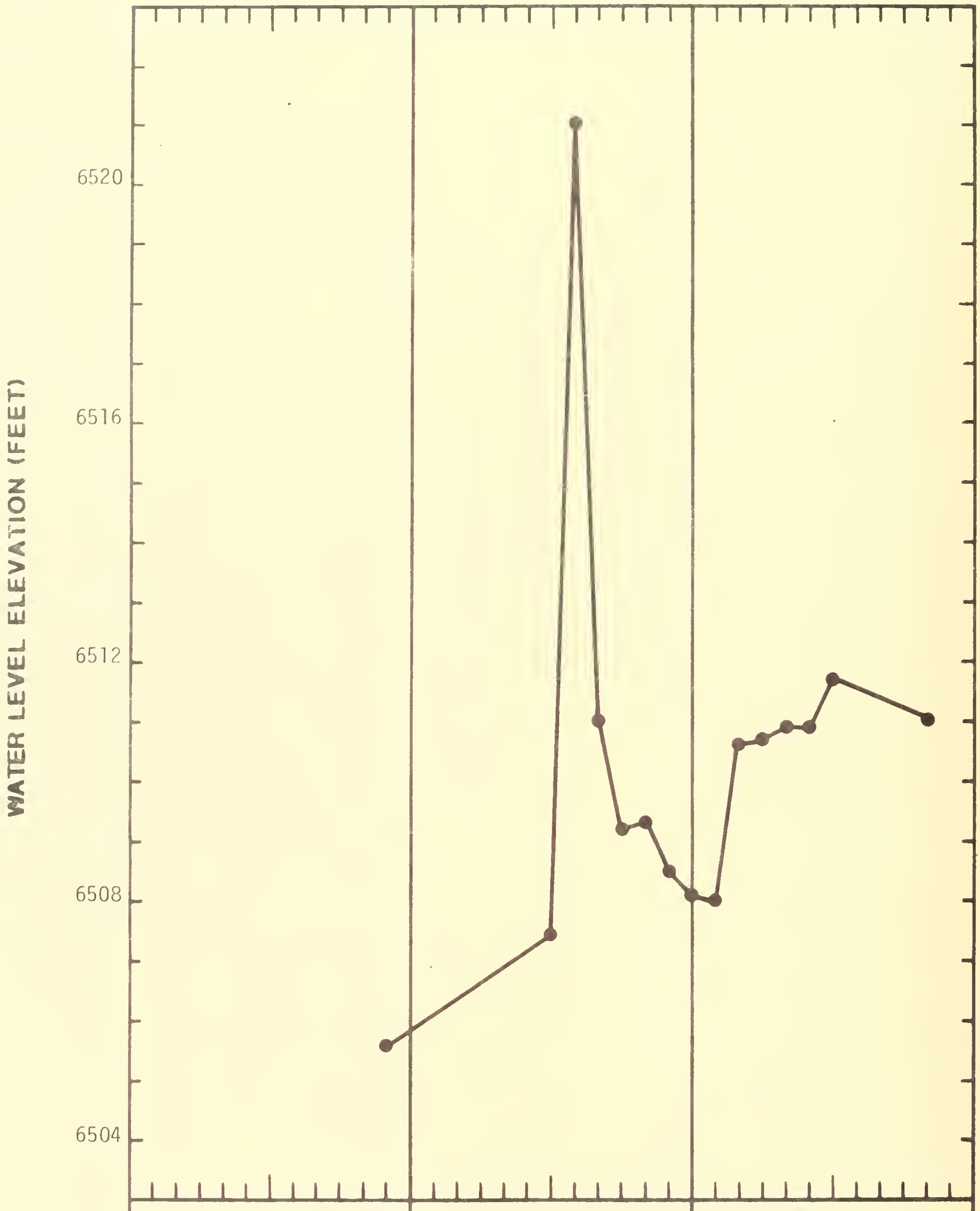


FIGURE A-46 WATER LEVEL DATA

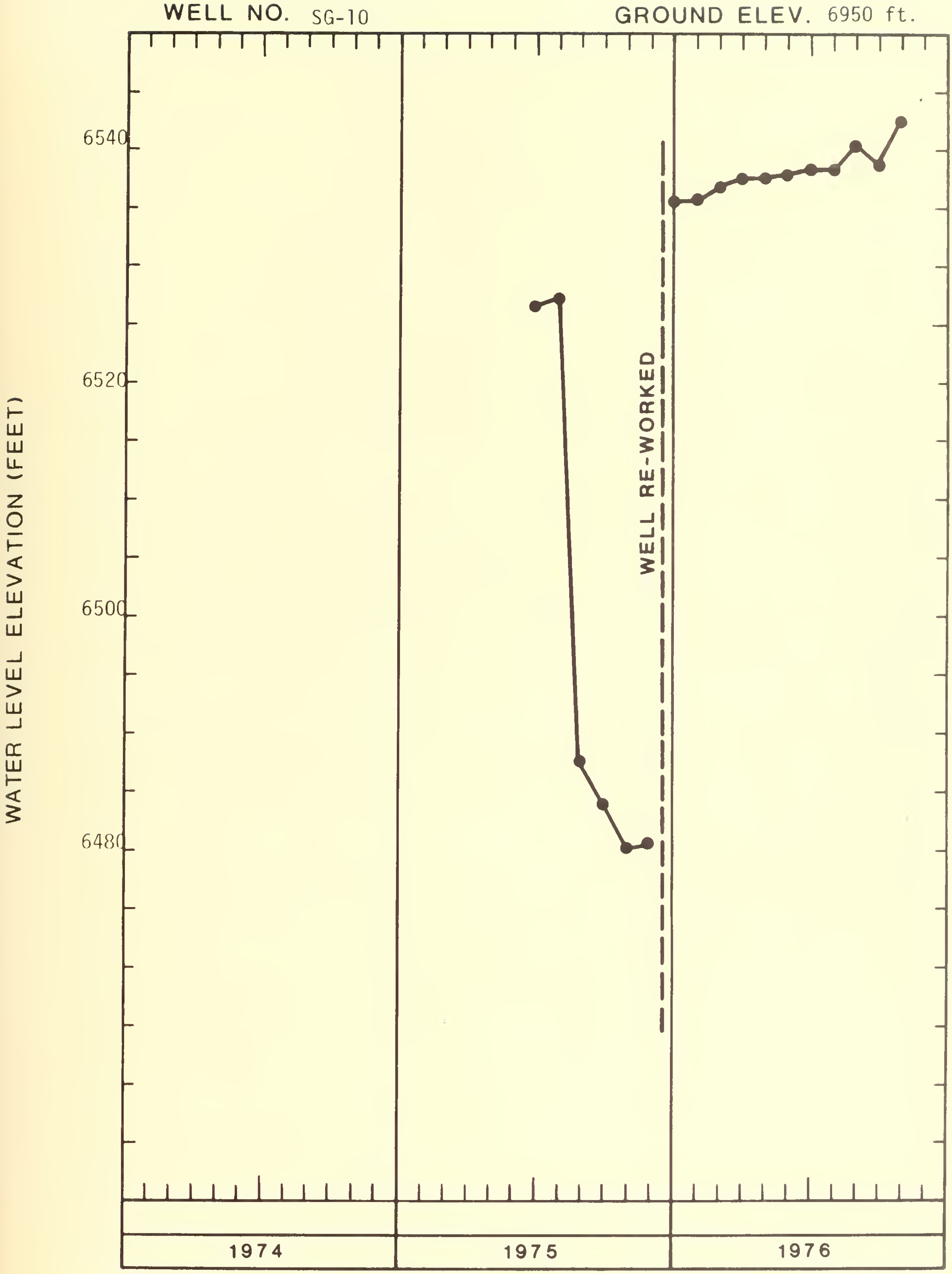


FIGURE A-47 WATER LEVEL DATA

WELL NO. SG-11 String 1R **GROUND ELEV.** 6905 ft.

FIGURE A-48 WATER LEVEL DATA

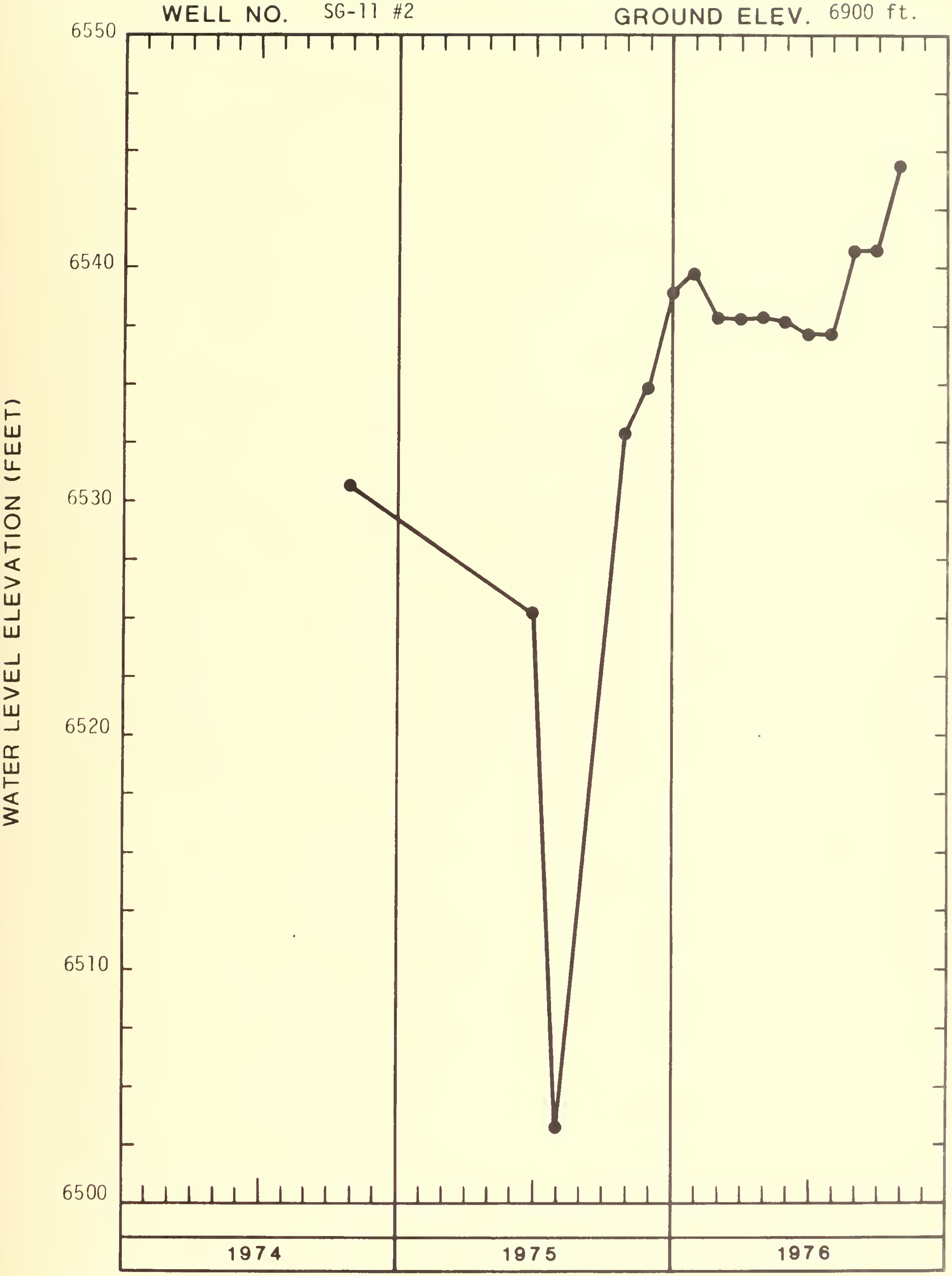


FIGURE A-49 WATER LEVEL DATA

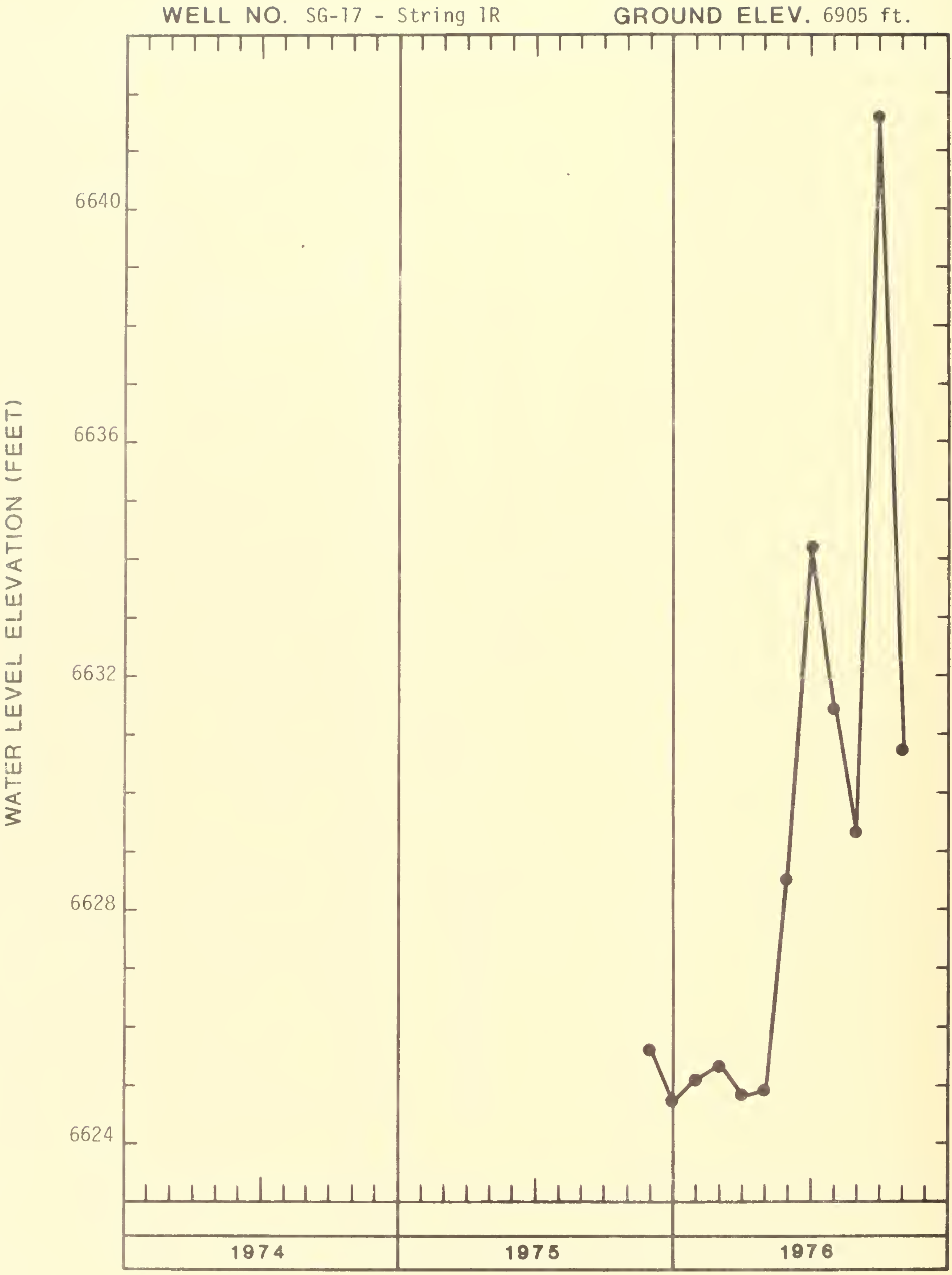


FIGURE A-50 WATER LEVEL DATA

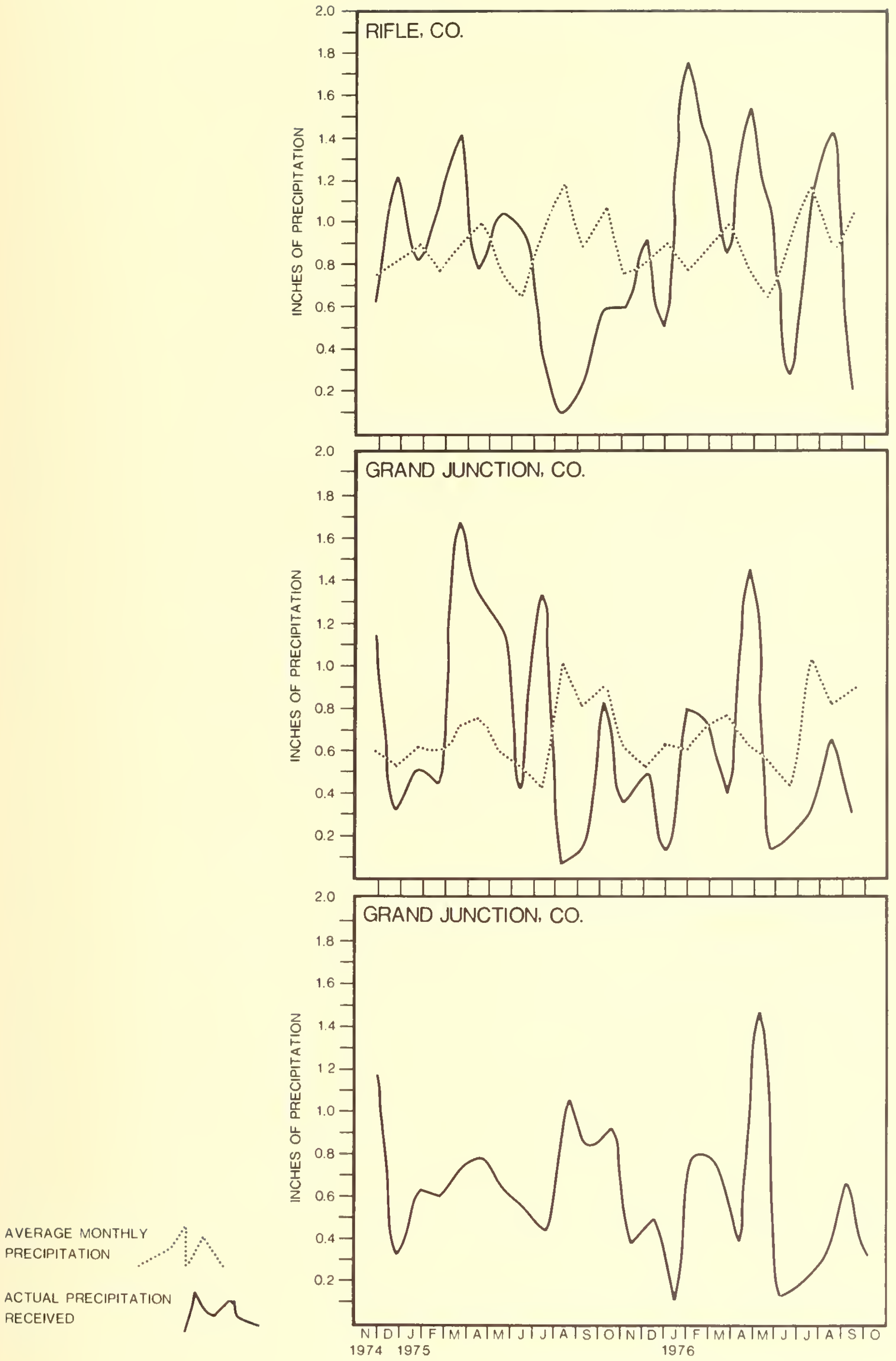


FIGURE A-51

TIME SERIES OF MONTHLY PRECIPITATION TOTALS FOR THE C-bTRACT, GRAND JUNCTION, AND RIFLE (INCHES OF PRECIPITATION)

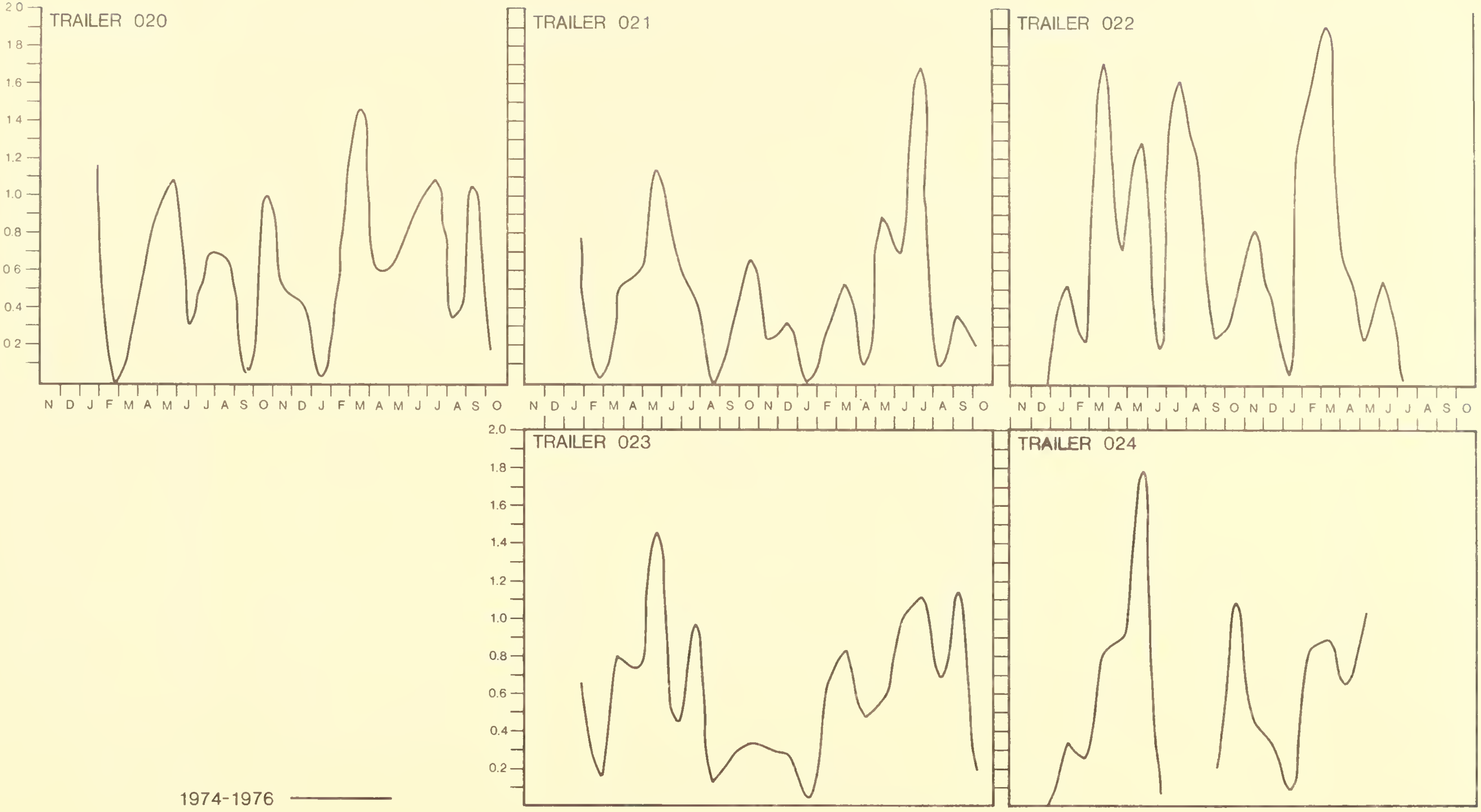


FIGURE A-52

TIME SERIES OF MONTHLY PRECIPITATION TOTALS FOR THE C-b TRACT, GRAND JUNCTION, AND RIFLE (INCHES OF PRECIPITATION)

Table A-1

ALLUVIAL WELL LEVELS, DEVIATIONS FROM THE MEAN

	A-1	A-2	A-3	A-5	A-6	A-7	A-8	A-9	A-10	A-11	A-12	Monthly Average All Wells
Mean	6235.9	6270.2	6372.1	6325.7	6327.6	6350.6	6384.2	6491.4	6564.5	6449.4	6637.8	
September 1974						0		+0.6	+1.1	-0.7	-0.9	0
October 1974	+0.6	-2.1	+2.0	-0.7	-2.5	-	+0.1	-	-	-	-	-0.4
December 1974	0	+1.4	+4.4	0	+0.3	+0.5	+1.3	+1.6	+2.6	+0.1	+1.2	+1.2
January 1975	-0.7	+1.6	+2.0	-0.1	-1.8	+0.2	+1.7	+0.9	+0.8	+0.2	0	+0.4
March 1975	-2.6	-1.2	-0.1	+0.2	-4.1	-0.7	-1.8	-1.1	-0.1	-1.1	+0.7	-1.1
June 1975	+2.1	+1.5	+5.2	+0.8	+4.9	+3.4	+1.8	+0.3	+4.8	-0.2	+0.7	+2.3
July 1975	+4.1	+1.2	+0.7	+0.2	+2.4	+5.4	+1.4	+0.2	+3.9	-0.3	-0.1	+1.7
August 1975	+4.0	+0.1	+2.0	0	+4.9	+3.4	+1.1	0	+0.2	-0.5	-0.8	+1.3
September 1975	+2.0	+1.7	+1.4	+0.1	-0.5	-0.3	-0.6	+0.1	+2.9	-0.5	-1.1	+0.5
October 1975	+0.8	+3.3	+0.2	+0.1	-2.5	+0.8	+0.3	+0.7	+2.6	-0.5	-0.3	+0.5
November 1975	-0.7	+3.6	-0.6	+0.2	-0.6	-2.3	-4.2	+0.6	+1.0	-0.5	-1.4	-0.4
December 1975	-0.4	-0.5	-1.2	0	-2.3	-2.3	-0.1	+0.4	+1.5	-0.2	-0.8	-0.5
January 1976	-2.1	-0.6	-2.4	-0.2	-3.1	-3.3	-0.4	+0.2	+1.2	0	-0.5	-1.0
February 1976	-2.1	-1.8	-3.0	-0.3	-3.5	-3.8	+0.4	+0.1	+0.5	+0.2	-0.2	-1.2
March 1976	-2.1	-1.7	-1.2	-0.3	-2.9	-2.9	+2.2	+0.4	+0.5	+0.8	+0.2	-0.6
April 1976	-2.1	-1.2	-3.0	-0.2	-3.0	-4.3	+1.6	+0.4	+0.5	+0.7	+1.1	-0.9
May 1976	-	-1.2	-3.7	+0.1	+3.2	-6.4	-0.4	-0.1	+0.9	+0.8	+1.6	-0.5
June 1976	-2.5	-1.2	-1.3	+0.5	+3.4	+3.6	-	+0.6	-2.3	+0.7	+1.7	+0.3
July 1976	+1.7	-1.7	+0.3	-0.3	+4.0	+6.3	-1.1	-0.4	-3.8	+1.3	+0.3	+0.6
August 1976	+2.3	-1.6	+0.3	-0.3	+4.8	+3.1	-0.3	-0.8	-4.7	+0.5	+0.8	+0.4
September 1976	+0.7	+0.8	-0.3	-0.2	-0.2	+1.1	+1.5	-1.2	-5.0	-0.4	-0.2	-0.3
October 1976	-2.1	-0.8	-1.5	+0.3	-1.2	-0.9	-1.9	-2.6	-4.3	-0.6	-0.8	-1.5
November 1976	-0.6	+0.1	+0.2	+0.4	+1.2	-1.0	-1.8	-0.1	-5.1	-0.8	-0.9	-0.8
Average Deviation	1.7	1.4	1.7	0.2	2.6	2.5	1.2	0.6	2.3	0.5	0.7	

Table A-2

UPPER AQUIFER WELL LEVELS, DEVIATIONS FROM MEAN

	Cb-2	Cb-4	AT-1C #3	SG-1 #2	SG-6 #3	SG-9 #2	SG-10A	SG-11 #3	SG-17 #2	SG-18A	SG-19	SG-21	Average
Mean	6410.6	6626.1	6547.6	6365.9	6556.6	6518.6	6576.0	6547.2	6639.4	6897.7	6381.8	6705.0	
October	+6.4	-10.1	-9.0					-3.2		-			-4.0
November	-6.6	-6.9	-12.3			+5.3		-		+3.3			-3.9
December	-11.8	-12.3	-			-		-		-			-
June	-	+0.8	-	+0.8	-7.7	+2.8	-3.8	-1.2	-0.9	+1.8		-5.1	-1.4
July	+3.4	+1.9	-	+1.6	-4.1	+3.6	-2.3	+2.0	+0.5	+3.3	+2.6	+8.9	+1.9
August	+7.5	+2.9	+2.5	+1.5	+2.7	+3.6	-1.3	-	+1.5	+2.4	+2.6	-1.7	+2.2
September	+5.2	+0.4	+0.5	+1.6	+2.0	+1.6	-2.5	-15.4	-0.9	+2.3	+2.6	-2.1	-0.4
October	-4.8	-0.4	+0.8	+1.3	+0.9	-0.9	-3.3	+1.1	+0.7	-1.0	+2.6	-1.3	-0.4
November	-3.7	-0.4	+1.4	+0.9	+2.4	-2.1	-2.0	+0.4	+1.1	-1.6	+2.6	-1.1	-0.2
December	-1.8	-0.3	-0.6	+1.1	+2.7	-2.5	-2.8	+2.6	0	-1.7	-	-1.2	-0.4
January	-2.3	+0.3	+1.2	+0.9	-0.1	-2.0	-3.5	+2.0	+0.4	-1.6	-2.8	-0.9	-0.7
February	+0.7	+1.0	+1.6	-1.5	-0.1	+1.6	+0.7	+1.7	+0.4	-1.7	-2.5	-1.3	0
March	+1.9	+1.4	+1.8	-1.5	-0.5	+2.2	-1.5	+1.6	+0.3	-1.3	-1.7	-1.2	+0.1
April	+1.0	+1.2	-1.2	-1.5	-0.4	+1.6	+1.8	+1.3	+0.3	-0.7	-2.0	-1.1	0
May	+2.6	+0.9	+2.2	-1.6	+2.3	+2.0	+2.0	+1.2	+1.4	-1.1	-1.5	-1.4	+0.7
June	+3.1	+6.8	+2.3	-1.9	+2.3	+2.3	+2.4	+0.9	+4.6	+3.8	-1.3	+0.7	+2.0
July	+2.8	+2.4	+1.4	-0.5	+2.5	-8.0	+2.9	+0.9	+1.9	-1.5	-0.4	-1.0	+0.3
August	+2.6	+2.3	+3.1	-0.5	-1.2	-8.0	+2.9	+1.0	-0.4	-1.5	+2.6	+4.8	+0.7
September	-2.5	+2.0	+1.8	-0.5	-1.6	-7.6	+3.4	+0.9	-9.8	-2.1	+2.6	+5.3	-0.7
October	-4.2	+6.6	+3.3	-0.1	-2.9	+3.6	+6.2	+1.3	-0.8	-1.2	-5.6	+0.2	+0.5

Table A-3

LOWER AQUIFER WELL LEVELS, DEVIATIONS FROM THE MEAN

	Cb-1	AT-1C #1	AT-1C #2	SG-1 #1	SG-8R	SG-10R	SG-11 #1R	SG-11 #2	SG-17 #1R	SG-9 #1	SG-6 #1	SG-6 #2	AT-1	Average
Mean	6404.6	6516.4	6517.4	6363.0	6532.0	6538.0	6491.6	6536.9	6628.8	6510.3	6492.7	6512.0	6517.2	
October 1974		-9.9	-7.4					-6.3						-7.9
November 1974		-7.5	-4.4					--		-4.7				-5.5
June 1975	+2.2	--	--					-11.9		-2.9	-5.6			-4.6
July 1975	+0.9	--	--							+10.7	-2.6			+3.0
August 1975	+1.5	-7.6	-7.0	+1.3						+0.7	-2.8	-7.9		-3.0
September 1975	-0.9	-6.3	-6.4	+2.1						-1.1	-3.7	-6.7	-5.4	-3.6
October 1975	-0.6	-3.5	-3.6	+3.0				-4.0		-1.0	-1.7	-4.1	-4.6	-2.2
November 1975	-0.5	-0.8	-0.9	-0.4				-2.1	-3.2	-1.8	-0.2	-1.6	-1.2	-1.3
December 1975	-1.0	-1.0	-0.4	+0.1		-2.6		+2.0	-4.1	-2.2	-0.8	-1.8	-3.0	-1.3
January 1976	0	+1.4	+1.0	+4.0	-4.2	-2.4	+7.4	+2.9	-3.7	-2.3	+0.4	+0.6	-3.0	-0.2
February 1976	-0.8	+2.4	+2.0	+2.6	-4.0	-1.2	-2.3	+0.9	-3.5	+0.3	+0.9	+1.3	+1.6	0
March 1976	-0.6	+0.8	+2.1	+2.6	-8.4	-0.5	-2.4	+0.9	-4.0	+0.4	+0.9	+1.2	+1.8	+0.2
April 1976	-0.8	+3.6	+3.1	+1.6	-10.0	-0.5	-2.4	+0.8	-3.9	+0.6	+1.1	+2.1	+1.9	-0.2
May 1976	-0.5	+3.2	+2.9	+1.3	-3.6	-0.1	-2.4	+0.7	-0.3	+0.6	+1.2	+2.2	+1.8	+0.5
June 1976	-0.3	+4.4	+3.4	-2.3	+6.0	+0.3	-2.4	+0.3	+5.4	+1.4	+1.5	+2.4	+2.4	+1.7
July 1976	-0.7	+4.0	+3.3	-4.0	+6.0	+0.2	-2.4	+0.4	+2.6	--	+2.4	+2.5	+2.5	+1.4
August 1976	-0.7	+4.0	+3.3	-4.0	+6.0	+2.2	+0.6	+3.8	+0.5	--	+2.7	+3.6	+2.5	+2.0
September 1976	+1.2	+4.0	+3.2	-3.7	+6.0	+0.4	+0.6	+3.8	+12.8	--	+2.7	+3.6	+2.5	+3.1
October 1976	+1.8	+8.4	+5.9	-4.0	+6.0	+4.5	+5.8	+7.4	+1.9	+0.7	+3.7	+2.2		+3.7
Average Deviation	0.9	4.3	3.5	2.5	6.0	1.4	2.9	3.2	3.8	2.1	2.1	2.9	2.6	

Table A-4

WATER QUALITY PARAMETERS - SPRINGS AND SEEPS

Date	Springs & Seeps, Location	Conductance	pH	TDS	Alpha Rad.	Beta Rad.	TOC	DOC	Phenols	Cyanide
5-75	a, Piceance, N of SG-19	--	7.4	1100	--	--	--			
10-74	S1, Mouth of Stewart	1300	7.9	1100	3	0	6			
5-76		1300	8.3	898	5	0				
6-76		1200	8.4	839	--	--	--	6.8		
10-76		1521	8.3	948	6.7	0			0.014	<0.1
10-74	S2, East Stewart	1100	8.0	880	2	0	3			
9-75		1200	8.4	970	1	1	<1			
5-76		1200	8.1	847	8.6	3				
10-76		1521	8.4	819	10	0			0.022	<0.1
10-74	S3, Mouth of Stewart	1200	7.6	970	3	0	4			
9-75		1400	8.4	1130	0	6	<1			
2-76		1450	8.5	967	--	--	--	3		
4-76		1300	8.3	1030	--	--	--	9.4		
5-76		1300	8.3	941	4.9	10	--	7.5	<.01	0.03
6-76		1200	8.5	846	--	--	--	2.3		
7-76		1400	7.8	1003	--	--	--	7		
8-76		1455	8.5	1015	--	--	--	5		
10-76		1559	8.4	960	8.8	0			0.011	<0.1
10-74	S4, Savage Cabin, Stewart	1100	7.8	800	4	0	3			
9-75		1100	8.4	840	8	0	<1			
5-76		1250	8.3	926	5.8	16				
10-74	S6, Mouth of Willow	1200	8.2	900	3	0	3			
5-75		1400	7.3	--	--	--	--			
9-75		1400	8.4	960	4	0	3			
5-76		1300	8.2	934	5.4	6				
10-76		1562	8.3	936	7.4	7			0.009	<0.1
10-74	S7, PL Ranch	1300	8.1	970	2	0	6			
9-75		1300	8.4	1100	20	30	<1			
5-76		1250	8.1	932	1.7	7				
10-76		1521	8.4	921	10	0			0.007	<0.1
10-74	S8, Willow at Scandard	1300	7.9	1000	4	0	3			
9-75		1200	8.3	1000	4	10	<1			
10-76		1467	8.4	872	5.8	0			0.037	<0.1
10-74	S9, Willow 3/4 above Scandard	1200	8.1	950	5	0	3			
9-75		1400	7.8	--	--	--	--			
2-76		1300	8.3	945	--	--	--	5		
4-76		1300	8.3	1003	--	--	--	6.7		
5-76		1200	8.2	865	3.9	2	--	4.2	<.01	0.02
6-76		1200	8.3	845	--	--	--	4.5		
7-76		1350	8.2	984	--	--	--	6		
8-76		840	8.3	547	--	--	--	3		
9-76		1495	8.4	986	--	--				
10-76		1505	8.4	860	11	10			0.031	<0.1
10-74	S10, Willow 2 above Scandard	1200	7.9	910	1	0	6			
5-75		1300	7.9	--	--	--	--		<.01	0.02
9-75		1200	8.3	940	5	9	<1			
5-76		1100	8.2	810	4.7	0	--	2.9		
6-76		1100	8.4	756	--	--	--	3.3		
7-76		1250	8.1	898	--	--	--	10		
10-76		1355	8.4	808	11	4			0.007	<0.1

Table A-5

MAJOR CONSTITUENTS - SPRINGS AND SEEPS

Date	Springs and Seeps, Location	Mg	NO_3	PO_4	K	Na	SiO_2	SO_4
5-75	a, Piceance, N of SG-19	78	0.5	<.1	--	240	21	370
10-74	S1, Mouth of Stewart	57	8.1	<.1	--	200	12	440
5-76		77			1.5	123	13	373
6-76		82	6.58	<.02	1.5	122	13	397
10-76		80	.09	<.01	1	122	17	401
10-74	S2, East Stewart	81	5.4	<.1	--	110	13	340
9-75		86	0.2	<.1	1.1	110	15	340
5-76		74			.8	113	15	354
10-76		76	2.1	.02	.8	111	17	354
10-74	S3, Mouth of Stewart	37	5.6	<.1	--	200	13	370
9-75		94	8.1	<.1	2.0	140	16	400
2-76		80	.51	.03	1.7	131	14	387
4-76		91	<.03	<.02	1.8	135	14	435
5-76		80	.8	.06	1.5	129	13	398
6-76		84	3.4	.02	1.7	129	14	415
7-76		93	5.72	.03	1.6	132	15	417
8-76		96	1.87	.02	1.9	138	21	415
10-76		83	1.2	<.01	1.8	135	17	424
10-74	S4, Savage Cabin, Stewart	93	6.0	<.1	--	90	13	290
9-75		77	7.3	<.1	1.5	100	15	300
5-76		76			1.3	129	15	401
10-74	S6, Mouth of Willow	63	2.7	<.1	--	160	15	360
5-75		85	0.8	0	2.3	140	21	360
9-75		100	0.7	<.1	2.2	140	17	350
5-76		79			2	133	17	346
10-76		85	1.6	<.01	2	128	19	374
10-74	S7, PL Ranch	64	2.9	<.1	--	150	16	380
9-75		92	6.9	<.1	1.9	130	17	380
5-76		82			1.4	133	16	357
10-76		85	1.2	<.01	1.5	130	17	381
10-74	S8, Willow at Scandard	63	1.1	<.1	--	140	13	350
9-75		84	4.8	<.1	2.0	110	15	330
10-76		78	.85	<.01	1.7	111	18	354
10-74	S9, Willow 3/4 above Scandard	46	1.7	<.1	--	150	14	350
9-75		79	0.3	0.03	1.3	130	20	340
2-76		80	.2	.02	1.1	120	16	358
4-76		91	<.03	<.02	1.1	124	17	370
5-76		76	.12	.02	1.1	120	16	318
6-76		84	.56	.02	1.1	122	17	362
7-76		94	.34	.03	1.3	120	17	356
8-76		51	<.02	<.02	.6	68	15	196
9-76		84	<.04	.03	1	120	19	366
10-76		81	.75	<.01	1	118	19	350
10-74	S10, Willow above Scandard	28	0.1	<.1	--	120	13	310
5-75		75	0.6	0.1	1.3	110	18	320
9-75		81	1.8	<.1	1.2	110	16	320
5-76		69	.8	.06	1.1	112	15	310
6-76		76	1.92	<.02	1.1	111	14	342
7-76		86	.28	<.02	1.1	109	14	341
10-76		76	.74	<.01	1	110	16	329

Table A-6

MAJOR CONSTITUENTS - SPRINGS AND SEEPS

Date	Springs & Seeps, Location	NH_3	HCO_3	Ca	CO_3	Cl	Li
5-75	a, Piceance N of SG-19	--	650	48	<.1	17	--
10-74	S1, Mouth of Stewart	0.1	520	100	<.1	4	<.5
5-76			454	81	2	3.5	<.5
6-76		.24	345	40	7.2	4	<.5
10-76		<.1	470	84	3	8	<.5
10-74	S2, East Stewart	<.1	500	82	<.1	5	<.5
9-75		0.2	420	78	5	5	<.5
5-76			433	75	--	.9	--
10-76		<.1	364	70	4	6	<.5
10-74	S3, Mouth of Stewart	<.1	520	92	<.1	5	<.5
9-75		0.4	460	83	4	5	<.5
2-76		<.02	512	86	6	8	<.5
4-76		<.05	510	91	5	5	<.5
5-76		.3	459	84	2	6.2	<.5
6-76		.01	321	33	5	5	<.5
7-76		<.01	537	74	--	4	<.5
8-76		.12	492	86	7	7	--
10-76		<.1	404	80	5	15	<.5
10-74	S4, Savage Cabin, Stewart	<.1	480	66	<.1	4	<.5
9-75		0.2	420	77	7	4	<.5
5-76			451	78	--	2	<.5
10-74	S6, Mouth of Willow	<.1	560	100	<.1	<4	<.5
5-75		--	610	96	0	11	0
9-75		0.4	480	97	4	10	<.5
5-76			537	81	--	9.7	<.5
10-76		<.1	465	79	2	17	<.5
10-74	S7, PL Ranch	<.1	520	120	<.1	<4	<.5
9-75		0.2	500	80	3	10	<.5
5-76			518	79	--	6.2	<.5
10-76		<.1	431	78	4	11	<.5
10-74	S8, Willow at Scandard	0.1	610	140	<.1	<4	<.5
9-75		0.2	450	78	4	8	<.5
10-76		<.1	424	84	5	10	<.5
10-74	S9, Willow 3/4 above Scandard	0.1	520	130	<.1	<4	<.5
9-75		--	590	100	0	9	0
2-76		<.02	537	92	3	10	<.5
4-76		<.05	580	102	4	7	<.5
5-76		.3	494	84	--	5.3	<.5
6-76		.03	415	42	3	9	<.5
7-76		.02	604	82	--	11	<.5
8-76		.12	321	54	2	2	--
9-76		.02	571	99	--	7	--
10-76		<.1	406	76	5	9	<.5
10-74	S10, Willow 2 above Scandard	0.1	540	160	<.1	1	<.5
5-75		--	540	100	0	9	0
9-75		0.2	460	84	3	6	<.5
5-76		.3	445	77	--	5.3	<.5
6-76		.01	353	28	3	7	<.5
7-76		.01	543	72	--	6	<.5
10-76		<.1	365	71	6	18	<.5

Table A-7

IMPORTANT TRACE ELEMENTS - SPRINGS AND SEEPS

Date	Springs & Seeps, Location	Al	As	Ba	Be	B	Cd	Cr	Co	Cu
5-75	a, Piceance N of SG-19	--	--	--	--	--	--	--	--	--
10-74	S1, Mouth of Stewart	.06	.003	.02	ND	1.4	ND	<.01	.002	.04
5-76		.02	.001	.02	ND	.03	ND	.07	<.007	.04
6-76		--	.001	--	--	--	--	--	--	--
10-76		.5	.010	.09	<.001	.02	ND	.03	<.006	.04
10-74	S2, East Stewart	.5	.004	.05	.002	1.2	ND	<.01	ND	.04
9-75		0.7	.002	.04	ND	0.1	ND	<.01	<.005	.02
5-76		.01	.001	.04	ND	.02	ND	.02	<.005	.02
10-76		.3	.005	.02	ND	.01	<.007	.02	.003	.05
10-74	S3, Mouth of Stewart	.3	.003	.01	ND	1.1	ND	<.01	.004	.03
9-75		3	.004	.02	ND	0.4	ND	<.01	ND	.04
2-76		.02	.01	.04	ND	.05	ND	.1	<.01	.02
4-76		--	<.05	--	--	--	--	--	--	--
5-76		.04	.001	.01	ND	.07	ND	.08	<.008	.01
6-76		--	.001	--	--	--	--	--	--	--
7-76		--	.001	--	--	--	--	--	--	--
8-76		--	.001	--	--	--	--	--	--	--
10-76		.1	.006	.1	<.001	.001	<.005	.02	.001	.09
10-74	S4, Savage Cabin, Stewart	0.1	ND	.05	.001	1.2	ND	<.01	.03	.2
9-75		0.3	.003	.02	ND	<.1	ND	<.01	<.005	.02
5-76		.09	.005	.02	ND	.06	ND	.07	<.003	.05
10-74	S6, Mouth of Willow	1.0	.03	.03	ND	1.6	ND	<.01	.01	.05
5-75		ND	ND	ND	--	0.1	--	--	--	--
9-75		0.4	.002	.06	ND	1.1	ND	<.01	<.007	.03
5-76		.02	.001	.01	ND	.04	ND	.05	.002	.007
10-76		.07	.003	.1	ND	.1	<.008	.02	<.003	.02
10-74	S7, PL Ranch	0.4	.004	.01	ND	1.6	ND	<.01	.002	.03
9-75		0.2	.003	.03	ND	0.2	ND	<.01	ND	.01
5-76		--	.001	.05	ND	.1	ND	.03	<.01	.009
10-76		1	.002	.08	ND	.02	ND	.005	.003	.04
10-74	S8, Willow at Scandard	0.2	ND	.06	ND	0.2	ND	<.01	.02	.2
9-75		--	.01	.04	ND	0.2	ND	<.01	ND	.01
10-76		.02	.002	.05	ND	.04	ND	.006	.004	.01
10-74	S9, Willow 3/4 above Scandard	0.2	.002	.05	ND	0.4	ND	<.01	.05	.1
9-75		ND	ND	ND	--	0.3	--	--	--	--
2-76		.004	.002	.05	<.001	.02	<.002	.01	<.002	.04
4-76		--	<.05	--	--	--	--	--	--	--
5-76		.01	.001	.02	ND	.08	ND	.06	<.003	.02
6-76		--	.001	--	--	--	--	--	--	--
7-76		--	.0005	--	--	--	--	--	--	--
8-76		--	.001	--	--	--	--	--	--	--
9-76		--	.001	--	--	--	--	--	--	--
10-76		.03	.005	.04	ND	.06	<.007	.01	<.002	.03
10-74	S10, Willow 2 above Scandard	2	.002	.05	ND	0.6	ND	<.01	.002	.03
5-75		.02	.001	ND	--	0.1	--	--	--	--
9-75		1	.001	.03	ND	0.1	ND	<.01	<.001	.003
5-76		.03	.001	.06	ND	.06	ND	.08	<.007	.03
6-76		--	.001	--	--	--	--	--	--	--
7-76		--	.0005	--	--	--	--	--	--	--
10-76		.03	.002	.02	ND	.2	ND	.01	<.005	.03

Table A-8

IMPORTANT TRACE ELEMENTS, SPRINGS AND SEEPS

Date	Springs & Seeps	F	Fe	Pb	Mn	Hg	Ni	Se	V	Zn
5-75	a	0.2	<.05	--	--	--	--	--	--	--
10-74	S1	0.9	1.8	<.05	0.2	.0011	.02	ND	.004	.04
5-76		.2	<.1	.04	.003	.0008	.02	ND	.01	.06
6-76		.2	<.1	--	--	<.00003	--	--	--	--
10-76		.2	<.1	<.01	.01	.00009	.02	<.004	.02	.1
10-74	S2	0.6	0.5	.01	.02	.0011	.004	ND	.005	.1
9-75		0.1	<.05	.01	.01	<.0001	.02	ND	.005	.04
5-76		.2	<.1	<.02	.002	<.00003	--	ND	.004	.02
10-76		.2	<.1	.009	.04	.00189	.05	<.002	.01	.06
10-74	S3	0.7	4.0	.02	.04	.002	.01	ND	.002	.3
9-75		0.2	0.2	.05	.007	.0004	.01	ND	.006	.07
2-76		.1	.3	.04	.005	.00003	.02	<.04	.006	.04
4-76		.2	<.1	--	--	--	--	--	--	--
5-76		.2	<.1	<.03	.007	<.00003	.01	ND	.009	.04
6-76		.2	<.1	--	--	<.00003	--	--	--	--
7-76		.2	<.1	--	--	.0006	--	--	--	--
8-76		.2	<.1	--	--	--	--	--	--	--
10-76		.2	<.1	.008	.01	.00044	.02	<.004	.004	.06
10-74	S4	0.6	7.8	.04	--	.001	.08	ND	.009	.1
9-75		0.1	.09	.05	--	.0003	<.03	<.002	.005	.02
5-76		.2	<.1	.01	.1	--	.006	ND	.003	.03
10-74	S6	2.1	<.05	<.03	.03	.0017	.01	ND	.004	.4
5-75		0.6	.01	.001	ND	--	--	.001	--	ND
9-75		0.4	<.05	<.01	.01	.0002	.009	.004	.005	.1
5-76		.5	<.1	.04	.004	.0001	.01	ND	.003	.02
10-76		.4	<.1	<.005	.009	.00013	.02	<.008	.006	.05
10-74	S7	1.5	.3	.03	.01	.0003	.009	ND	.004	.08
9-75		0.3	<.05	.01	.007	<.0001	.003	ND	.003	.02
5-76		.4	<.1	.03	.01	<.00003	.01	ND	.002	.03
10-76		.3	<.1	<.004	.01	.00011	.02	<.003	.01	.05
10-74	S8	1.7	0.1	ND	.1	.0001	.01	ND	.003	.05
9-75		0.2	<.05	<.004	.04	<.0001	.007	<.001	<.001	.01
10-76		.3	<.1	<.008	.02	.00011	.03	<.003	.002	.03
10-74	S9	1.5	.84	ND	.05	.0001	.02	ND	.005	.2
9-75		0.5	.01	.001	.02	--	--	ND	--	ND
2-76		.3	.4	.04	.02	.00003	.007	<.003	.002	.1
4-76		.4	<.1	--	--	--	--	--	--	--
5-76		.4	<.1	<.02	.006	<.00003	.004	ND	.002	.05
6-76		.2	<.1	--	--	.00003	--	--	--	--
7-76		.3	<.1	--	--	<.00003	--	--	--	--
8-76		.2	<.1	--	--	--	--	--	--	--
9-76		.4	<.1	--	--	--	--	--	--	--
10-76		.2	<.1	<.006	.02	.00007	.01	<.006	.004	.1
10-74	S10	1.4	.47	.02	.06	.0014	.005	ND	.002	.2
5-75		0.4	ND	.001	ND	--	--	ND	--	ND
9-75		0.3	<.05	.004	.002	.0002	.003	ND	.002	.01
5-76		.4	<.1	.04	.003	.00003	.01	ND	.003	.07
6-76		.2	<.1	--	--	.00003	--	--	--	--
7-76		.3	<.1	--	--	<.00003	--	--	--	--
10-76		.3	<.1	<.01	.008	.00013	.009	<.004	.005	.1

Table A-9

MINOR TRACE ELEMENTS - SPRINGS AND SEEPS

Date	Springs & Seeps	Y	Sr	Rb	Br	Ge	Ga	Ti	Sc	W
2-75	a	--	--	--	--	--	--	--	--	--
10-74	S1		1	.005	.02			.1	.005	
5-76			1.7		.01		.005	.2	<.005	
6-76		--	1.4	--	--	--	--	--	--	--
10-76			1.2	.01	.03		.002	.2	<.004	<.002
10-74	S2	.002	3	.01	.02			.06	.006	
9-75			.9	.01	.03			.3	<.002	
5-76			2.1	.002	.01			.2	<.004	
10-76			1.1	.003	.05		<.001	.04	<.002	
10-74	S3		2	.008	.04			.08	.006	
9-75			2	.01	.08			.4	<.002	
2-76		.002	1.6	.01	.006			.1	<.008	<.02
4-76		--	1.6	--	--	--	--	--	--	--
5-76			1.7	.004	.01			.09	<.01	
6-76		--	1.4	--	--	--	--	--	--	--
7-76		--	2.0	--	--	--	--	--	--	--
8-76		--	1.9	--	--	--	--	--	--	--
10-76			1.2	.02	.04		<.002	.06	<.002	<.003
10-74	S4	.003	4	.03	.03	.007	.006	.1	.006	
9-75			1	.01	.02			.2	<.002	
5-76			3	.001	.02			.3	<.005	
10-74	S6		5	.04	.03	.008	.005	.3	.01	
5-75		--	4.5	--	--	--	--	--	--	--
9-75			2	.01	.03			.1	<.005	
5-76			2.1		.02			.09	<.02	
10-76			1.7	.007	.02		<.001	.04	<.002	
10-74	S7		2	.01	.01		.006	.2	.006	
9-75			1	.005	.05			.6	<.001	
5-76			2.3		.004		.005	.08	<.006	
10-76			1.8	.002	.02		<.001	.05	<.002	
10-74	S8		3	.009	.04	.006		.2	.007	
9-75			4	.008	.01		<.001	.3	<.001	
10-76			1.6	.004	.03		<.001	.02	.003	
10-74	S9		1	.005	.02			.2	.01	
9-75		--	4.4	--	--	--	--	--	--	--
2-76		<.001	1.2	.05	.01		.002	.2	<.002	
4-76		--	1.8	--	--	--	--	--	--	--
5-76			2.1		.01			.05	<.009	<.01
6-76		--	1.7	--	--	--	--	--	--	--
7-76		--	2.4	--	--	--	--	--	--	--
8-76		--	1.4	--	--	--	--	--	--	--
9-76		--	2.2	--	--	--	--	--	--	--
10-76			1.4	.02	.01		.001	.05	<.002	<.001
10-74	S10	<.001	1	.005	.01			.02	.004	
5-75		--	3.8	--	--	--	--	--	--	--
9-75			3	.004	.05			.6	<.001	
5-76			1.7		.009			.4	<.01	.02
6-76		--	.6	--	--	--	--	--	--	--
7-76		--	1.9	--	--	--	--	--	--	--
10-76			1.4	.002	.02		<.002	.07	<.004	<.007

Table A-10

MINOR TRACE ELEMENTS - SPRINGS AND SEEPS

Date	Springs and Seeps, Location	U	Th	Cs	I	Sb	Ag	Mo	Zr
5-75	a, Piceance, N of SG-19	--	--	--	--	--	--	--	--
10-74	S1, Mouth of Stewart								
5-76								.01	
6-76		--	--	--	--	--	--	--	--
10-76				.007	.004			.04	.002
10-74	S2, East Stewart								
9-75				.01	.005			.04	.02
5-76								<.02	.003
10-76				<.001	.001			.02	.002
10-74	S3, Mouth of Stewart								
9-75				.02	.06			.05	.04
2-76					.005			.04	.007
4-76		--	--	--	--	--	--	--	--
5-76					.004			<.02	
6-76		--	--	--	--	--	--	--	--
7-76		--	--	--	--	--	--	--	--
8-76		--	--	--	--	--	--	--	--
10-76				.003	.002			.04	.002
10-74	S4, Savage Cabin, Stewart							.01	
9-75				.001	.002			.03	.003
5-76				.002	.001			<.005	.002
10-74	S6, Mouth of Willow				.005			.01	
5-75		--	--	--	--	--	--	--	--
9-75								.05	.002
5-76					.005			<.03	
10-76				<.001	.001		<.001	.02	.002
10-74	S7, PL Ranch				.006				
9-75				<.001	<.001	<.001		.01	
5-76					.004				
10-76				<.001	<.001	.001		.02	<.001
10-74	S8, Willow at Scandard					.006		.06	
9-75				<.001	<.001			.02	<.001
10-76				<.001	.003			.01	.002
10-74	S9, Willow 3/4 above Scandard				.002			.2	
9-75		--	--	--	--	--	--	--	--
2-76		.004		.006	<.001			.03	.003
4-76		--	--	--	--	--	--	--	--
5-76					.003			<.009	<.004
6-76		--	--	--	--	--	--	--	--
7-76		--	--	--	--	--	--	--	--
8-76		--	--	--	--	--	--	--	--
9-76		--	--	--	--	--	--	--	--
10-76				.001	.002			.02	<.003
10-74	S10, Willow 2 above Scandard				.001			.02	
5-75		--	--	--	--	--	--	--	--
9-75		<.001		<.001	.004	<.001		--	.001
5-76					.004				
6-76		--	--	--	--	--	--	--	--
7-76		--	--	--	--	--	--	--	--
10-76				<.002	.005			.05	.003

Table A-11

WATER QUALITY PARAMETERS - ALLUVIAL WELLS

Date	Well	Conductance	pH	TDS	Alpha Rad.	Beta Rad.	TOC	DOC
10-74	A-1	1800	7.8	1300	4	0	7	--
5-75		1800	8.4	1200	2	0	8	--
9-75		1800	8.4	1300	13	11	2	--
2-76		1700	8.4	1269	--	--	--	6
4-76		1600	8.3	1285	--	--	--	9.3
5-76		1500	8.3	1163	3.4	11	--	3.7
6-76		1650	8.7	1092	--	--	--	4.2
7-76		1800	8.3	1252	--	--	--	--
8-76		1825	8.4	1271	--	--	--	9
9-76		1200	8.4	749	--	--	--	--
10-76		1929	8.6	1167	18	0	--	--
10-74	A-2	1200	7.4	1100	2	0	7	--
5-75		1000	8.6	820	6	0	2	--
9-75		1100	8.6	850	5	12	2	--
5-76		1100	8.3	769	.1	0	--	2.4
10-76		1286	7.8	805	4.5	7	--	--
10-74	A-3	1500	7.5	1000	0	0	7	--
9-75		1400	8.4	990	1	6	3	--
2-76		1350	8.3	950	--	--	--	3
4-76		1280	8.1	1022	--	--	--	8.2
5-76		1200	8.1	894	2.1	3	--	2.8
6-76		1200	8.4	807	--	--	--	3.9
7-76		1450	8.1	972	--	--	--	7
8-76		1460	8.3	993	--	--	--	--
9-76		1460	8.3	993	--	--	--	--
10-76		1559	8.4	902	11	8	--	--
10-74	A-5	1500	7.8	1200	0	0	7	--
5-75		1300	8.5	940	6	0	3	5
9-75		1300	8.3	880	4	0	2	--
5-76		1200	8.2	851	2.9	0	--	7.8
10-76		1521	8.2	941	6.9	13	--	--
10-74	A-6	1500	7.4	1200	3	0	7	--
9-75		1400	8.5	1200	7	0	6	--
2-76		1650	8.4	1147	--	--	--	5
4-76		1400	8.2	1080	--	--	--	9.2
5-76		1450	8.2	1039	3	0	--	5.1
6-76		1350	8.6	912	--	--	--	5.6
7-76		1500	8.1	1018	--	--	--	7
8-76		1515	8.4	1010	--	--	--	--
9-76		1550	8.3	986	--	--	--	--
10-76		1578	8.0	992	11	11	--	--
10-74	A-7	1200	8.4	1200	14	6	8	--
5-75		1000	8.2	780	4	0	9	--
9-75		1100	8.3	850	7	0	3	--
2-76		1250	8.3	844	--	--	--	7
4-76		1150	8.3	878	--	--	--	8.5
5-76		1200	8.2	774	11	0	--	--
6-76		1025	8.5	696	--	--	--	--
7-76		1200	8.3	805	--	--	--	4.7
8-76		1290	8.3	819	--	--	--	11
9-76		1330	8.4	853	--	--	--	--
10-76		1341	8.2	855	8.1	0	--	--
10-74	A-8	1400	7.6	1200	0	9	8	--
5-75		1100	8.5	880	10	0	9	--
9-75		1300	8.7	1200	7	0	3	--
5-76		1300	8.3	895	5.7	0	--	--
10-76		1386	8.1	973	8.0	9	--	--
10-74	A-9	1100	7.4	860	0	0	6	--
5-75		1000	8.5	720	6	0	2	--
9-75		1200	8.2	960	2	0	1	--
5-76		950	8.4	713	1.3	0	--	--
10-76		1188	8.2	790	3.5	0	--	--
10-74	A-10	1300	8.0	1000	2	0	3	--
5-75		1200	8.2	940	9	0	7	-
9-75		1400	8.3	1100	5	0	3	--
5-76		1250	8.2	967	2.6	0	--	--
10-76		1355	8.2	929	6.1	0	--	--
10-74	A-11	1500	7.4	1100	5	0	3	--
5-75		1300	8.4	1000	7	0	1	--
9-75		1400	8.4	1100	3	3	2	--
5-76		1300	8.4	1045	9	0	--	--
10-76		1646	8.2	1074	6.4	5	--	--
10-74	A-12	1500	7.3	1200	2	0	3	--
5-75		1400	8.1	1100	4	0	7	--
9-75		1500	8.5	1100	3	0	2	--
5-76		1350	8.2	1091	3.3	11	--	--
10-76		1738	8.0	1082	6.3	0	--	--

Table A-12

MAJOR CONSTITUENTS - ALLUVIAL WELLS

Date	Well	Mg	NO_3	PO_4	K	Na	SiO_2	SO_4
10-74	A-1	80	0.3	<.1	--	270	17	530
5-75		86	<.1	<.1	2	240	15	420
9-75		100	0.4	<.1	2	250	17	440
2-76		93	.05	.03	1.6	246	17	463
4-76		95	.08	<.02	1.7	254	16	480
5-76		84	<.04	.04	1.7	240	17	447
6-76		80	.14	.02	1.6	240	16	460
7-76		94	<.02	.02	1.6	240	18	474
8-76		100	.04	.07	1.6	244	21	470
9-76		49	<.04	.04	.9	149	12	274
10-76		85	1.8	<.01	2	240	19	469
10-74	A-2	65	0.6	1.1	--	260	22	410
5-75		77	0.9	<.1	1	160	30	210
9-75		83	2.9	0.1	1	140	27	200
5-76		68	<.04	.14	.7	138	24	218
10-76		73	.65	<.01	.7	138	30	232
10-74	A-3	45	3.0	0.3	--	250	18	400
9-75		91	2.0	<.1	1	120	15	330
2-76		80	.46	.03	1.1	127	16	346
4-76		94	.03	<.02	1.3	127	15	370
5-76		77	<.04	.06	1.3	123	16	346
6-76		80	1.08	<.02	1.3	124	15	360
7-76		93	1.59	.03	1.4	124	15	361
8-76		97	<.02	.04	1.3	124	19	352
9-76		86	.12	.03	1.3	125	19	359
10-76		83	.61	<.01	1	120	17	358
10-74	A-5	64	2.2	0.2	--	290	17	500
5-75		82	1.5	<.1	3	170	20	260
9-75		91	7.8	<.1	1	130	13	370
5-76		64	<.04	.13	2.1	157	17	263
10-76		73	1.35	<.01	2	160	17	290
10-74	A-6	70	3.5	0.3	--	300	20	400
9-75		94	5.2	<.1	5	180	18	330
2-76		86	.28	.06	1.7	177	18	385
4-76		93	.09	<.02	1.6	183	17	360
5-76		77	.20	.06	1.5	188	19	370
6-76		79	2.43	.07	1.6	177	17	353
7-76		92	.5	.05	1.6	177	18	321
8-76		92	.02	.06	1.6	170	21	305
9-76		79	<.04	.08	1.5	168	21	307
10-76		78	.18	<.01	2	168	20	300
10-74	A-7	20	4.3	0.4	--	380	41	480
5-75		53	1.5	<.1	1	140	15	260
9-75		62	2.9	<.1	1	140	14	300
2-76		63	.16	.03	.9	137	14	282
4-76		64	.03	<.02	1.1	142	15	300
5-76		55	.22	.12	1	141	14	230
6-76		49	2.88	<.02	1.2	137	15	281
7-76		56	2.32	<.02	1.1	135	15	281
8-76		62	<.02	<.02	1.1	134	19	258
9-76		51	<.04	.45	1.0	138	17	307
10-76		55	.60	<.01	1	142	17	313
10-74	A-8	60	3.5	<.1	--	290	16	480
5-75		91	5.2	<.1	2	93	15	350
9-75		90	4.2	<.1	2	130	15	370
5-76		80	.56	.09	1.6	122	14	346
10-76		83	.83	<.01	2	124	15	403
10-74	A-9	57	6.6	<.1	--	150	14	360
5-75		72	4.6	<.1	2	93	16	260
9-75		92	1.5	<.1	1	130	16	360
5-76		64	2.88	.08	.8	98	11	255
10-76		69	.65	<.01	.7	102	15	300
10-74	A-10	79	9.1	<.1	--	160	14	450
5-75		99	0.6	<.1	2	110	15	430
9-75		92	6.8	<.1	2	190	11	420
5-76		88	2.08	.04	1.4	134	15	379
10-76		83	1.2	<.01	1	106	15	418
10-74	A-11	85	3.1	<.1	--	180	14	480
5-75		100	1.4	<.1	2	140	13	440
9-75		110	3.3	<.1	2	140	15	450
5-76		103	.16	.07	1.6	145	12	444
10-76		98	1.7	.04	2	142	15	472
10-74	A-12	53	2.9	<.1	--	730	15	480
5-75		110	0.9	<.1	2	150	15	490
9-75		120	2.9	<.1	2	140	15	490
5-76		110	<.04	.12	1.4	143	14	453
10-76		98	1.0	.02	2	142	15	446

Table A-13

MAJOR CONSTITUENTS - ALLUVIAL WELLS

Date	Well	NH_3	HCO_3	Ca	CO_3	Cl	OH	Li
10-74	A-1	<.1	660	80	<1	15	<.1	<.5
5-75		0.3	630	69	12	12	<.1	<.5
9-75		0.3	620	78	23	19	<.1	<.5
2-76		<.02	708	78	6	14	--	<.5
4-76		<.05	690	73	9	15	--	<.5
5-76		15.5	595	59	7	12	--	--
6-76		.01	503	18	12	15	--	<.5
7-76		.01	709	56	2	15	--	<.5
8-76		.13	678	75	8	15	--	--
9-76		.12	426	42	4	6	--	--
10-76		<.1	539	57	11	16	--	<.5
10-74	A-2	0.6	590	52	<1	10	<.1	<.5
5-75		1.1	580	44	10	4	<.1	<.5
9-75		0.2	520	47	10	6	<.1	<.5
5-76		.4	525	44	9	4.4	--	--
10-76		.66	567	43	--	6	--	<.5
10-74	A-3	<.1	560	58	<1	8	<.1	<.5
9-75		<.1	550	100	5	7	<.1	<.5
10-76		<.02	555	92	3	10	--	<.5
4-76		<.05	600	102	<1	16	--	<.5
5-76		.2	500	81	--	.9	--	--
6-76		.01	375	29	4	7	--	<.5
7-76		<.01	601	71	--	9	--	<.5
8-76		.17	567	102	9	8	--	--
9-76		.02	581	99	8	8	--	--
10-76		<.1	446	88	3	10	--	<.5
10-74	A-5	<.1	520	36	<1	15	<.1	<.5
5-75		0.7	620	76	18	12	<.1	<.5
9-75		0.2	440	80	5	6	<.1	<.5
5-76		.1	561	68	--	3	--	--
10-76		<.1	647	68	--	12	--	<.5
10-74	A-6	0.1	670	30	<1	17	<.1	<.5
9-75		0.5	580	69	10	19	<.1	<.5
2-76		<.02	726	90	9	21	--	<.5
4-76		<.05	670	83	<1	12	--	<.5
5-76		.2	616	69	--	9	--	<.5
6-76		.06	482	21	9	16	--	<.5
7-76		<.01	689	52	ND	16	--	<.5
8-76		.11	659	74	9	12	--	--
9-76		<.01	640	74	6	13	--	--
10-76		<.1	683	73	--	14	--	<.5
10-74	A-7	0.1	400	16	18	11	<.1	<.5
5-75		5.2	460	71	<1	23	<.1	<.5
9-75		0.2	360	54	4	27	<.1	<.5
2-76		<.02	476	80	3	29	--	<.5
4-76		<.05	500	83	3	23	--	<.5
5-76		.3	494	65	--	23	--	<.5
6-76		.1	320	24	5	25	--	<.5
7-76		<.01	471	54	5	24	--	<.5
8-76		.12	466	83	7	24	--	--
9-76		<.01	479	78	6	18	--	--
10-76		<.1	494	69	--	13	--	<.5
10-74	A-8	0.1	630	56	<1	4	<.1	<.5
5-75		2.7	460	84	12	5	<.1	<.5
9-75		0.2	460	94	15	5	1.7	<.5
5-76		.3	491	82	2	4.4	--	<.5
10-76		<.1	531	78	--	6	--	<.5
10-74	A-9	0.2	450	49	<1	4	<.7	<.5
5-75		2.7	440	45	9	5	<.1	<.5
9-75		0.2	480	81	--	6	<.1	<.5
5-76		.3	411	70	8	2	--	<.5
10-76		<.1	464	68	--	6	--	<.5
10-74	A-10	<.1	440	69	<1	5	<.1	<.5
5-75		0.1	460	48	<1	4	<.1	<.5
9-75		0.6	450	64	4	23	<.1	<.5
5-76		.3	531	80	--	6	--	<.5
10-76		<.1	445	80	--	6	--	<.5
10-74	A-11	<.1	480	61	<1	4	<.1	<.5
5-75		0.4	490	50	6	6	<.1	<.5
9-75		0.2	450	78	5	7	<.1	<.5
5-76		.3	512	78	--	7	--	<.5
10-76		<.1	519	80	--	8	--	<.5
10-74	A-12	0.1	580	100	<1	4	<.1	<.5
5-75		1.1	500	50	<1	10	<.1	<.5
9-75		<.1	540	100	11	6	<.1	<.5
5-76		.3	567	85	--	4	--	<.5
10-76		<.1	580	86	--	6	--	<.5

Table A-14

IMPORTANT TRACE ELEMENTS - ALLUVIAL WELLS

Date	Well	Al	As	Ba	Be	B	Cd	Cr	Co	Cu
10-74	A-1	.32	.005	.2	<.001	.6	ND	<.01	.02	.05
5-75		.06	<.002	.04	ND	.19	ND	<.01	ND	.01
9-75		.9	.006	.02	ND	.3	ND	.1	ND	.01
2-76		.02	--	.02	ND	.01	ND	.02	<.006	.02
4-76		--	--	--	--	--	--	--	--	--
5-76		--	.001	--	--	--	--	--	--	--
6-76		--	.001	--	--	--	--	--	--	--
7-76		.02	.001	.01	ND	.1	ND	.01	<.01	.02
8-76		--	.001	--	--	--	--	--	--	--
9-76		--	.001	--	--	--	--	--	--	--
10-76		.02	.002	.02	ND	.08	ND	.01	.002	.08
10-74	A-2	.34	.01	.1	<.001	1.7	ND	<.01	.05	.03
5-75		3	.002	.2	ND	0.1	ND	<.01	<.007	.02
9-75		.5	ND	.02	ND	.2	ND	<.1	ND	.01
5-76		--	<.001	--	--	--	--	--	--	--
10-76		.05	.001	.1	ND	.001	.003	.002	.001	.02
10-74	A-3	.14	.004	.2	.001	.7	ND	<.01	.02	.1
9-75		3.	ND	.02	<.002	.1	ND	<.1	ND	.02
2-76		.05	--	.03	ND	.009	ND	.03	<.01	.1
4-76		--	<.05	--	--	--	--	--	--	--
5-76		--	.001	--	--	--	--	--	--	--
6-76		--	.001	--	--	--	--	--	--	--
7-76		.03	.001	.05	ND	.03	ND	.02	.005	.04
8-76		--	.002	--	--	--	--	--	--	--
9-76		--	.001	--	--	--	--	--	--	--
10-76		.2	.003	.06	ND	.1	<.006	.007	<.003	.02
10-74	A-5	.06	.05	.6	ND	1.2	ND	<.01	.04	.1
5-75		.01	.003	.02	ND	.25	ND	<.01	<.002	<.01
9-75		.4	.004	.05	ND	.5	ND	<.01	ND	.02
5-76		--	.002	--	--	--	--	--	--	--
10-76		.02	.005	.01	ND	.1	ND	.009	.002	.03
10-74	A-6	<.05	.004	.03	ND	1.4	ND	<.01	.004	.09
9-75		--	<.002	.06	ND	.6	ND	<.01	<.001	.01
2-76		.02	--	.03	<.001	.08	ND	.04	.008	.1
4-76		--	<.05	--	--	--	--	--	--	--
5-76		--	.001	--	--	--	--	--	--	--
6-76		--	.002	--	--	--	--	--	--	--
7-76		.1	.002	.01	ND	.1	ND	.02	<.004	.02
8-76		--	.001	--	--	--	--	--	--	--
9-76		--	.002	--	--	--	--	--	--	--
10-76		--	.004	.02	ND	.06	ND	.01	<.002	.03
10-74	A-7	<.05	<.01	.4	ND	1.4	ND	<.01	.004	.09
5-75		.1	<.002	.04	ND	.25	ND	<.01	ND	.005
9-75		0.7	.003	.08	ND	.5	ND	<.01	<.002	.04
2-76		.3	--	.08	ND	.3	ND	.04	<.006	.05
4-76		--	<.05	--	--	--	--	--	--	--
5-76		--	.001	--	--	--	--	--	--	--
6-76		--	.001	--	--	--	--	--	--	--
7-76		.02	.001	.05	ND	.1	ND	.03	<.005	.01
8-76		--	.001	--	--	--	--	--	--	--
9-76		--	.002	--	--	--	--	--	--	--
10-76		.03	.003	.03	ND	.08	ND	--	--	.09
10-74	A-8	<.05	.004	.1	<.001	.7	ND	<.01	.01	.07
5-75		.1	<.002	.04	ND	.17	ND	<.01	<.006	.02
9-75		.3	.005	.04	ND	<.1	ND	<.01	<.002	.04
5-76		--	.001	--	--	--	--	--	--	--
10-76		.09	.002	.02	ND	.06	<.009	.03	<.003	.009
10-74	A-9	<.05	.003	.2	.001	.7	ND	<.01	.02	.01
5-75		.1	.003	.02	ND	.18	ND	<.01	<.002	.005
9-75		.3	.008	.03	ND	.7	ND	<.01	<.006	.02
5-76		--	.001	--	--	--	--	--	--	--
10-76		.1	.002	.01	ND	.06	.005	.01	<.001	.04
10-74	A-10	.25	.001	.05	<.001	.7	ND	<.01	.003	.03
5-75		.3	.003	.02	ND	.17	ND	<.01	<.002	.01
9-75		--	.008	.03	ND	.8	ND	<.01	<.003	.01
5-76		--	.001	--	--	--	--	--	--	--
10-76		.1	.002	.04	ND	.002	ND	.01	.001	.03
10-74	A-11	.52	.009	.1	ND	.6	ND	<.01	.02	.2
5-75		.1	.003	.03	ND	.4	ND	<.01	.002	.02
9-75		.1	.002	.02	ND	.5	ND	<.01	<.001	.04
5-76		--	.001	--	--	--	--	--	--	--
10-76		.02	.004	.03	ND	.08	ND	.01	.003	.02
10-74	A-12	.17	.008	.04	ND	1.2	ND	<.01	.009	.03
5-75		.1	<.002	.02	ND	5.2	ND	<.01	ND	.005
9-75		.1	.009	.07	ND	.2	ND	<.1	ND	.03
5-76		--	.001	--	--	--	--	--	--	--
10-76		.2	.003	.05	ND	.01	<.03	.01	<.01	.04

Table A-15

IMPORTANT TRACE ELEMENTS - ALLUVIAL WELLS

Date	Well	F	Fe	Pb	Mn	Hg	Ni	Se	V	Zn
10-74	A-1	3.4	9.4	.03	.5	.0003	.05	ND	.02	.5
5-75		1.2	<.05	<.01	.03	.0002	.008	.004	<.002	.2
9-75		.7	.09	<.01	.1	<.0001	.01	ND	.006	.02
2-76		.7	<.1	.08	<.1	--	.01	.03	.002	.02
4-76		.9	<.1	--	.4	--	--	--	--	--
5-76		.6	<.1	--	.4	--	--	--	--	--
6-76		.6	<.1	--	.4	--	--	--	--	--
7-76		.8	<.1	<.02	.4	--	.03	ND	.002	.02
8-76		.8	<.1	--	.4	--	--	--	--	--
9-76		.4	<.1	--	.4	--	--	--	--	--
10-76		1.	<.1	<.01	.4	.00006	.01	<.006	.001	.02
10-74	A-2	5	3.5	.03	1.5	.0002	.05	ND	.02	.05
5-75		2.0	<.05	.02	0.2	.0001	.01	ND	.002	1.
9-75		1.5	.2	.01	.09	<.0001	.01	ND	<.002	.01
5-76		1.6	.1	--	.2	--	--	--	--	--
10-76		1.8	<.1	<.002	.2	.00002	--	<.001	<.001	.05
10-74	A-3	1.9	<.05	.03	2.2	.0003	.07	ND	.01	.3
9-75		.36	.3	.01	.01	.0001	.01	ND	.006	.05
2-76		.3	.2	.02	<.1	--	.02	<.007	.006	.03
4-76		.4	<.1	--	<.1	--	--	--	--	--
5-76		.4	<.1	--	<.1	--	--	--	--	--
6-76		.3	<.1	--	<.1	--	--	--	--	--
7-76		.3	<.1	.04	<.1		.008	ND	.003	.02
8-76		.4	<.1	--	<.1	--	--	--	--	--
9-76		.4	<.1	--	<.1	--	--	--	--	--
10-76		.4	<.1	<.006	<.1	.00097	.01	<.002	.001	.07
10-74	A-5	1.5	<.05	.07	2.3	.0001	.09	.06	.03	1.
5-75		.5	<.05	.01	.01	.0004	.004	ND	.005	.7
9-75		.2	<.05	.02	.004	<.0001	.006	ND	.008	.02
5-76		.4	<.1	--	<.1	--	--	--	--	--
10-76		.4	<.1	<.008	<.1	.00006	.006	<.003	.004	.04
10-74	A-6	1.9	<.05	.1	.3	.0017	.02	ND	.002	.2
9-75		.36	.2	.003	.2	<.0001	.003	ND	.003	.02
2-76		.3	.2	.02	<.1	--	.03	.02	.009	.02
4-76		.4	<.1	--	.2	--	--	--	--	--
5-76		.5	<.1	--	.1	--	--	--	--	--
6-76		.3	<.1	--	.1	--	--	--	--	--
7-76		.4	<.1	<.02	.1	--	.02	ND	.003	.06
8-76		.4	<.1	--	.1	--	--	--	--	--
9-76		.4	<.1	--	.1	--	--	--	--	--
10-76		.5	<.1	<.01	.1	.00017	.02	<.004	.006	.05
10-74	A-7	1.9	<.05	<.01	.12	.00017	.02	ND	.006	.2
5-75		.2	<.05	<.01	.003	.048	.003	ND	.003	.03
9-75		.13	<.05	.01	.02	.0002	.008	.004	.004	.1
2-76		<.1	.3	.01	<.1	--	.03	<.02	.03	.03
4-76		.2	<.1	--	<.1	--	--	--	--	--
5-76		.2	<.1	--	<.1	--	--	--	--	--
6-76		.2	<.1	--	<.1	--	--	--	--	--
7-76		.2	<.1	<.03	<.1	--	.007	ND	.006	.02
8-76		.2	<.1	--	<.1	--	--	--	--	--
9-76		.2	<.1	--	<.1	--	--	--	--	--
10-76		.1	<.1	.01	<.1	.00007	--	<.003	.002	.04
10-74	A-8	.8	<.05	.02	2.1	.0003	.01	ND	.03	.06
5-75		.2	<.05	.02	.006	.0013	.02	.004	.005	.3
9-75		.2	<.05	.01	.006	.0001	.008	.003	.005	.2
5-76		.2	<.1	--	<.1	--	--	--	--	--
10-76		.2	<.1	<.01	<.1	.00042	.01	<.004	.006	.05
10-74	A-9	.8	<.05	.01	.7	.0001	.04	ND	.02	.1
5-75		.2	.14	.01	.007	.043	.004	ND	.005	.4
9-75		.3	<.05	.01	.009	<.0001	.009	ND	.005	1.
5-76		.2	.1	--	<.1	--	--	--	--	--
10-76		.2	<.1	.005	<.1	.00011	.01	.002	.009	.09
10-74	A-10	.8	.17	.01	.92	<.0001	.02	ND	.009	.05
5-75		.2	<.05	.03	.01	.0032	.02	<.007	.003	2.
9-75		.3	<.05	.009	.1	.0004	.008	ND	.002	.02
5-76		.3	.1		<.1	--	--	--	--	--
10-76		.2	<.1	<.004	<.1	.00006	.004	<.002	.004	.04
10-74	A-11	.5	1.3	.2	.52	.0003	.1	ND	.2	.4
5-75		.2	.05	.01	.03	.0011	.009	ND	.006	.07
9-75		.2	<.05	.004	.01	.0002	.004	ND	.003	.02
5-76		.2	.1	--	<.1	--	--	--	--	--
10-76		.2	<.1	<.008	<.1	.00023	.01	<.003	.005	.07
10-74	A-12	.7	2.8	.07	.09	.0002	.02	ND	.01	.4
5-75		1.7	<.05	.01	.003	.0024	.01	ND	<.002	.3
9-75		.2	<.05	<.02	.02	--	.02	ND	.008	1.
5-76		.2	.1	--	<.1	--	--	--	--	--
10-76		.2	<.1	<.02	<.1	.00102	.02	<.008	.001	.05

Table A-16

MINOR TRACE ELEMENTS ALLUVIAL WELLS

Date	Well	Cs	I	Mo	Zr	Y	Sr	Rb	Br	Ge	Ga	Ti	Sc
10-74	A-1		.004	.02			1	.05	.03			1.	.01
5-75		.007	.03	.04	.02		.4	.003	.03			.02	<.002
9-75		.02	.02	.02			1	.01	.08			.08	<.002
2-76		<.001	.005	.04	.02		1.4	.003	.01		<.002	.06	<.002
4-76		--	--	--	--	--	1.3	--	--	--	--	--	--
5-76		--	--	--	--	--	1.6	--	--	--	--	--	--
6-76		--	--	--	--	--	.9	--	--	--	--	--	--
7-76		.003	.01	.04			1.8	.002	.04		.004	.1	<.008
8-76		--	--	--	--	--	1.8	--	--	--	--	--	--
9-76		--	--	--	--	--	.8	--	--	--	--	--	--
10-76		<.001	.002	.02	.002		1.3	.002	.03		.002	.03	<.004
10-74	A-2			.005	.005	.003	2	.02	.02	.003	.01	.4	.005
5-75			.003		<.002		10.	.02	.03		<.002	.07	<.004
9-75			.002	.04			2	.01	.03			.3	<.002
5-76		--	--	--	--	--	3.3	--	--	--	--	--	--
10-76		<.001	.001	.02	.001		1.9	.003	.006		.001	.05	<.001
10-74	A-3		.003	.02		.006	2	.01	.02			--	.005
9-75			.002	<.007			1	.01	.05			.8	<.002
2-76		.007	.003	--	.006	.002	2.0	.01	.008		<.002	.3	<.002
4-76		--	--	--	--	--	1.9	--	--	--	--	--	--
5-76		--	--	--	--	--	2.7	--	--	--	--	--	--
6-76		--	--	--	--	--	1.7	--	--	--	--	--	--
7-76		.004	.006	.02			2.6	.006	.008		.005	.06	<.005
8-76		--	--	--	--	--	2.6	--	--	--	--	--	--
9-76		--	--	--	--	--	2.3	--	--	--	--	--	--
10-76		.001	.004	.02	.002	<.001	2.2	.003	.01		<.001	.1	<.003
10-74	A-5		.01	.02	.01	.004	4	.05	.09	.03	.03	1.	.01
5-75		<.002	.02	.01	<.002		1	.003	.02			.03	<.002
9-75				.06			1	.02	.02			.2	<.008
5-76		--	--	--	--	--	1.4	--	--	--	--	--	--
10-76		<.001	.01	.03	.002		.9	.004	.04			.04	<.003
10-74	A-6		.002			.001	3	.004	.02			.08	.005
9-75			.001	.04	.001		.9	.004	.006			.6	<.002
2-76			.006	.05	.005	<.003	1.8	.004	.05		<.003	.09	<.003
4-76		--	--	--	--	--	1.4	--	--	--	--	--	--
5-76		--	--	--	--	--	1.8	--	--	--	--	--	--
6-76		--	--	--	--	--	1.2	--	--	--	--	--	--
7-76		<.003	.01	.03			1.8	.003	.03		<.004	.1	<.009
8-76		--	--	--	--	--	1.7	--	--	--	--	--	--
9-76		--	--	--	--	--	1.5	--	--	--	--	--	--
10-76		<.002	.002	.04	.004		1.3	.002	.03		<.002	.07	<.005
10-74	A-7		.002	.01		.001	2	.03	.05	.005	.002	.1	.003
5-75		.01	.02		.04		1	.006	.05			.03	<.002
9-75			.002	.04	.002		2	.01	.1			.5	<.004
2-76		.002		.09	.006	<.001	1.8	.01	.08			1.	<.003
4-76		--	--	--	--	--	1.7	--	--	--	--	--	--
5-76		--	--	--	--	--	2.8	--	--	--	--	--	--
6-76		--	--	--	--	--	1.4	--	--	--	--	--	--
7-76		<.004	.005	.02			2.0	.006	.04	.005	.006	.04	<.01
8-76		--	--	--	--	--	2.0	--	--	--	--	--	--
9-76		--	--	--	--	--	1.8	--	--	--	--	--	--
10-76		.001	.004	.07	.003		2.0	.004	.06			.1	<.003
10-74	A-8	.002	.001	.01	.004	.004	.8	.03	.009	.002	.001	.3	.004
5-75		.03	.02		.02		2	.03	.08				<.005
9-75			.002	.04			2	.01	.03				<.004
5-76		--	--	--	--	--	2.2	--	--	--	--	--	--
10-76		<.002	.002	.02	.002		1.1	.002	.02		<.002	.03	<.004
10-74	A-9		.002	.02	.01	.002	--	.02	.009		.004	.3	.002
5-75			.006	.02	<.002		1	.006	.02			.03	<.002
9-75				.09			2	.02	.02			.7	<.005
5-76		--	--	--	--	--	2.3	--	--	--	--	--	--
10-76		<.001	.002	.02	<.001		1.1	.005	.02	<.001	<.001	.03	<.002
10-74	A-10		.001	--	.002	.002	.7	.02	.02			.1	.002
5-75		.007	.004		.004		2	.003	.02			.08	<.002
9-75		.02	.03	.01	.004		1	.01	.1			.6	<.002
5-76		--	--	--	--	--	2.5	--	--	--	--	--	--
10-76		.001	.002	.02	.001		1.1	.005	.02		.001	.03	<.002
10-74	A-11			.2			3	.06	.05			2.	.009
5-75		--	--	--	--	--	3	.004	.03	--	--	.03	<.005
9-75			.005	.02			2	.002	.06			.1	<.001
5-76		--	--	--	--	--	3.2	--	--	--	--		
10-76		<.001	.002	.1	.001		1.8	.003	.02		.002	.05	<.003
10-74	A-12					.007	3	.009	.05			.4	.02
5-75		.007	.003	.02			1	.006	.02		<.002	.01	.006
9-75		.03	.01	.06			3	.04	.08			1.	<.004
5-76		--	--	--	--	--	3.2	--	--	--	--	--	--
10-76		.006	.004	.03	.04		1.8	.005	.01		.004	.06	<.009

Table A-17

WATER QUALITY PARAMETERS - UPPER AQUIFER

Well	Conductance	pH	Total Dissolved Solids	P Alkalinity	MO Alkalinity	Hardness	Gross Alpha Radiation	Gross Beta Radiation	Total Organic Carbon
Cb-2	1600	8.9	1000	--	--	39	2	0	<1
	1600	8.7	1000	60	360	24	12	0	4
	1600	9.1	980	39	400	48	3	0	<1
	1583	8.9	1025	--	--	--	7.8	0	--
Cb-4	800	8.4	520	--	--	180	1	0	<1
	800	8.7	550	10	320	170	16	0	3
	800	8.8	540	15	390	190	5	0	1
	890	8.6	557	--	--	--	0	2	--
AT-1c, String 3	1200	8.6	750	--	--	150	2	2	<1
	1200	8.5	880	<.1	660	300	8	0	1
	1400	8.5	920	20	360	340	1	0	<3
	1400	8.4	935	--	--	--	--	--	--
	1595	8.6	955	--	--	--	11	0	--
SG-1, String 2	1200	8.7	890	10	500	270	8	0	<1
	1200	8.7	800	22	440	60	6	0	<1
	1000	8.3	840	--	--	--	--	--	--
	1347	8.6	834	--	--	--	3.9	8	--
SG-6, String 3	1500	8.3	1200	10	370	560	1	0	9
	1600	8.4	1000	15	320	630	3	0	4
	1500	8.3	1129	--	--	--	4.7	2	--
	1584	8.7	--	--	--	--	4.2	7	--
SG-8, String 2	2100	8.8	1400	30	990	180	11	0	3
	1800	8.8	1100	64	810	190	7	0	4
SG-9, String 2	1600	8.5	1300	--	--	570	2	2	8
	2000	8.1	1400	<.1	560	640	8	0	5
	1800	8.4	1300	--	540	720	2	0	<1
	1500	8.1	1391	--	--	--	--	--	--
	1822	8.3	1318	--	--	--	.7	0	--
SG-10A	1300	8.6	940	10	360	370	6	0	<1
	1300	8.4	840	5	320	380	6	0	<1
	1458	8.3	905				10	4	--
SG-11, String 3	1600	8.9	1200	39	600	340	7	0	3
	2000	8.7	1300	39	820	280	1	0	8
	1890	8.4	1164	--	--	--	8	31	--
SG-17, String 2	4200	8.8	3100	98	1500	84	21	0	4
	2500	9.0	1100	34	740	72	4	0	3
	1200	8.8	749	--	--	--	--	--	--
	1661	8.9	941	--	--	--	2.4	0	--
SG-18A	--	8.2	540	--	--	--	8	3	<1
	900	8.7	620	10	390	240	4	0	<1
	800	8.8	520	15	360	190	0	0	<1
	1019	8.8	597	--	--	--	4.9	7	--
SG-19	2800	8.4	1800	--	--	29	8	33	<1
	2800	8.6	1800	45	430	36	20	0	7
	2600	9.0	1800	44	1400	32	6	0	3
	2864	8.8	1741	--	--	--	0	0	--
SG-20	2800	8.7	1900	70	1500	32	12	0	8
	2600	9.0	1700	49	1400	32	6	0	3
	2500	8.4	1745	--	--	--	4	32	--
	2845	8.8	1715	--	--	--	2.2	0	--
SG-21	1000	8.5	590	20	380	160	9	0	2
	900	8.9	540	10	380	140	3	0	<1
	1055	8.7	612	--	--	--	1.6	16	--

Table A-18

MAJOR CONSTITUENTS - UPPER AQUIFER

Well	Mg	NO_3	PO_4	K	Na	SiO_2	SO_4
Cb-2	4	0.3	<.1	3	380	17	330
	3	1.2	<.1	6	350	19	300
	4	0.3	<.1	3	370	15	320
	4	.36	<.02	2	367	15	325
Cb-4	23	0.2	<.1	<1	130	23	140
	25	0.4	0.1	1	150	32	130
	27	0.8	<.1	1	140	20	140
	26	.06	<.02	.7	140	25	142
AT-1c, String 3	23	<.1	<.1	4	220	18	230
	45	0.5	<.1	4	230	13	300
	54	1.5	<.1	1	210	19	370
	50	.04	.04	2.6	200	19	370
	45	<.02	<.01	2	228	19	372
SG-1, String 2	43	<.1	<.1	1	230	21	240
	56	0.2	<.1	1	220	19	200
	48	.04	.02	.5	200	17	234
	53	.10	<.02	.7	204	20	239
SG-6, String 3	99	0.5	<.1	1	180	15	520
	120	0.2	<.1	1	180	20	350
	88	.82	.07	.8	178	15	510
	90	.02	.02	.8	181	9	506
SG-8, String 2	27	0.4	<.1	2	510	16	120
	25	0.4	<.1	1	430	13	31
SG-9, String 2	100	0.4	<.1	5	270	20	430
	150	0.4	0.4	5	220	22	520
	140	0.2	<.1	5	210	23	460
	129	.04	<.02	2.9	200	23	522
	133	.08	<.02	2	195	30	497
SG-10A	50	<.1	<.1	1	180	24	380
	58	0.1	<.1	1	190	21	360
	58	.03	.02	.7	186	25	410
SG-11, String 3	70	<.1	<.1	5	350	4	260
	51	0.3	0.1	11	410	14	140
	57	.12	.04	5	348	17	152
SG-17, String 2	7	1.9	<.1	9	1200	28	99
	8	0.2	<.1	3	44	13	35
	2.2			3	296	7.5	91
	3	.06	.03	1.7	330	13	21
SG-18A	30	0.2	--	<1	140	23	84
	37	0.1	0.2	1	150	21	130
	29	0.2	<.1	1	150	19	77
	35	<.04	<.02	.3	148	26	131
SG-19	3	<.1	<.1	--	760	9	<4
	3	<.1	<.1	1	780	9	23
	3	0.2	<.1	1	910	7	<4
	3	.03	.03	.9	760	13	4
SG-20	3	0.9	<.1	1	770	7	27
	3	2.1	<.1	1	760	7	<4
	2.9	.38	.15	.8	752	8	<4
	3	2.9	.03	.9	737	11	5
SG-21	25	0.6	0.2	1	190	15	80
	20	0.6	<.1	1	180	14	79
	24	.08	<.02	.3	183	17	14

Table A-19

MAJOR CONSTITUENTS - UPPER AQUIFER

Well	NH_3	HCO_3	Ca	CO_3	Cl	OH	Li
Cb-2	0.5	500	6	24	10	<.1	<.5
	0.5	550	3	46	11	<.1	<.5
	0.6	500	5	22	11	<.1	<.5
	.19	558	6	18	12	--	<.5
Cb-4	0.4	350	22	5	2	<.1	<.5
	0.4	400	23	8	7	<.1	<.5
	0.6	340	20	10	7	<.1	<.5
	.14	344	24	22	6	--	<.5
AT-1c String 3	0.2	450	15	9	7	<.1	<.5
	1.1	460	44	9	6	<.1	<.5
	0.8	410	51	7	7	<.1	<.5
	1.8	451	52	3.3	9	--	--
	.22	478	30	8	10	--	<.5
SG-1 String 2	0.5	580	29	24	18	<.1	<.5
	0.4	510	30	12	9	<.1	<.5
	1.5	573	41	3	8	--	<.5
	.37	539	27	11	8	--	<.5
SG-6 String 3	1.8	440	74	6	49	<.1	<.5
	0.8	440	78	6	29	<.1	<.5
	2.4	461	72	4.2	27	--	<.5
	.28	407	55	10	30	--	<.5
SG-8 String 2	1.6	1300	20	42	38	<.1	<.5
	0.9	1100	18	30	13	<.1	<.5
SG-9 String 2	0.2	740	117	12	49	<.1	<.5
	0.8	820	84	<1	22	<.1	<.5
	0.5	640	77	6	19	<.1	<.5
	1.1	793	100	--	19	--	<.5
	.32	677	92	6	17	--	<.5
SG-10A	1.7	440	57	12	13	<.1	<.5
	0.8	400	58	3	8	<.1	<.5
	.16	357	37	7	4	--	<.5
SG-11 String 3	0.7	820	16	36	53	<.1	<.5
	2.0	1100	23	24	46	<.1	<.5
	2.48	1010	43	11	19	--	<.5
SG-17 String 2	7.9	2100	7	60	514	<.1	3.1
	1.9	890	21	32	77	<.1	<.5
		604	4	15	19	--	<.5
	.43	883	9	28	20	--	<.5
SG-18A	--	470	24	--	3	--	0.3
	1.0	460	29	18	4	<.1	<.5
	0.6	420	19	11	3	<.1	<.5
	3.1	411	26	17	4	--	<.5
SG-19	0.1	1800	7	66	10	<.1	<.5
	1.1	2000	5	24	11	<.1	<.5
	1.5	1600	5	76	14	<.1	<.5
	1.2	1780	5	42	12	--	<.5
SG-20	1.4	2000	4	32	13	<.1	<.5
	1.0	1600	4	74	13	<.1	<.5
	4.1	1870	5.6	20	12	--	<.5
	.6	1780	5	42	12	--	<.5
SG-21	0.4	500	19	9	2	<.1	<.5
	0.4	420	16	16	2	<.1	<.5
	3.0	465	20	11	4	--	<.5

Table A-20

IMPORTANT TRACE ELEMENTS - UPPER AQUIFER

Well	Al	As	Ba	Be	B	Cd	Cr	Co	Cu
Cb-2, Fall '74	--	.02	.04	<.001	2.9	ND	.3	.002	3
Spring '75	--	.02	.1	ND	.1	.004	<.01	.008	.05
Fall '75	.5	.005	.02	ND	1.6	ND	<.01	<.001	.004
	.03	.005	.03	ND	.1	ND	.02	.002	.02
CB-4	--	.01	.02	<.001	2.8	ND	.03	.002	.5
	.3	.02	.2	ND	.4	.008	<.01	.006	.09
	.5	.005	.03	ND	<.1	<.01	<.01	<.001	.007
	.04	.005	.1	ND	.07	ND	<.01	<.001	.02
AT-1c, String 3	.9	.06	.02	ND	1.3	ND	.006	.002	.03
	.08	.02	.06	<.001	.16	ND	<.01	ND	.02
	.07	.04	.05	ND	.3	ND	<.01	ND	.005
		.013							
	.02	.004	.08	ND	.2	<.01	.02	<.005	.02
SG-1, String 2	.9	.03	.04	<.002	.42	ND	<.01	<.002	.05
	4.0	.004	.02	ND	.8	ND	<.01	ND	.04
	.02	.006	.02	ND	.03	ND	.007	<.003	.01
	.02	.009	.06	ND	.3	<.02	.004	.002	.01
SG-8, String 2	.04	.03	.6	ND	1.9	ND	<.01	<.001	.01
	.4	.02	.1	<.001	1.0	<.003	<.01	<.001	.01
SG-9, String 2	.7	.009	.07	.003	1.5	ND	<.01	.01	.03
	.05	.01	.1	ND	0.4	ND	<.01	.003	.05
	.3	.003	.03	ND	1.0	ND	<.01	<.002	.03
	.007	.005	.01	<.001	.04	ND	.01	.002	.01
	.03	.020	.03	ND	.07	<.01	.02	<.007	.01
SG-6, String 3	.5	.009	.06	ND	.35	ND	<.01	<.001	.03
	.005	.004	.02	ND	.6	ND	<.01	.001	.003
	.01	.001	.2	ND	.05	ND	.03	<.003	.003
	.04	.005	.05	ND	.02	ND	.006	<.005	.04
SG-11, String 3	.04	.02	ND	ND	1.5	ND	<.01	<.004	.009
	.4	.006	.03	ND	1.9	ND	<.01	<.001	.007
	.03	.050	.2	<.001	.6	<.01	.01	<.006	.02
SG-10A	.06	.006	.02	ND	3.2	ND	<.01	<.002	.005
	3.0	.03	.04	ND	.3	ND	<.01	.003	.03
	.1	.006	.04	ND	.01	ND	.01	<.006	.01
SG-17, String 2	.07	.03	.1	ND	18.	ND	<.01	<.003	.01
	.1	.02	.3	ND	6.2	ND	<.01	<.001	.007
	.02	.02	.06	ND	.2	ND	<.02	<.001	.02
	.06	.008	.1	<.001	.3	ND	.007	<.004	.007
SG-18A	.5	.02	.03	ND	1.4	ND	--	.001	.02
	.03	.006	.04	ND	.70	ND	<.01	<.002	.01
	.2	.006	.04	ND	.7	ND	<.01	<.008	.01
	.04	.003	.05	ND	.1	ND	.01	<.009	.02
SG-19	--	<.001	.2	ND	2.0	ND	.002	<.001	.08
	.05	.002	.2	ND	1.6	ND	<.01	<.002	.05
	.3	.001	.1	ND	1.4	ND	<.01	<.002	.01
	.003	.001	.3	<.001	.2	ND	.002	<.002	.008
SG-20	.04	.004	.3	ND	1.6	ND	<.01	<.004	.03
	.5	.004	.3	<.001	2.2	ND	<.01	ND	.02
	.003	.003	.2	<.001	.4	ND	--	<.003	.02
	.02	<.002	.4	<.001	3.	ND	.005	<.01	.03
SG-21	.06	.006	.1	ND	0.4	ND	<.01	<.003	.005
	.1	.008	.009	<.001	.2	ND	<.01	<.002	.01
	.04	.008	.09	ND	.4	<.01	.009	<.008	.01

Table A-21

IMPORTANT TRACE ELEMENTS - UPPER AQUIFER

Well	F	Fe	Pb	Mn	Hg	Ni	Se	V	Zn
Cb-2	2.9	.5	.02	.1	--	.02	ND	.002	.4
	4.0	1.2	.07	.1	.0004	.2	.002	.003	.1
	.9	.2	<.002	.01	<.0001	.003	ND	<.001	.003
	1.8	.3	.007	<.1	.00013	.01	.005	<.001	.01
Cb-4	1.0	.3	<.01	.1	--	.02	ND	.001	.07
	.9	<.05	.02	.02	.0002	.08	ND	.001	1.0
	.3	.07	.02	.04	<.0001	.02	.001	<.001	.04
	.6	<.1	<.02	<.1	.00012	.006	<.007	.001	.03
AT-1c, String 3	6.4	.28	.01	.2	.0008	.01	ND	.001	.03
	4.0	<.05	.01	.04	.0002	<.001	<.004	<.001	.07
	4.0	.1	.01	.02	<.0001	.007	<.001	<.001	.04
	3.1	1.1		.2	--				
	4.3	<.1	<.01	.1	.00007	.008	.002	.001	.03
SG-1, String 2	3.0	<.05	.02	.03	.0004	.02	.004	.003	.1
	3.3	.2	.003	.04	<.0001	.003	<.002	<.001	.01
	3.2	.1	.05	<.1	<.00003	.01	ND	.002	.02
	3.	<.1	.007	<.1	.0029	.01	.01	<.001	.07
SG-8, String 2	15.	<.05	.01	.04	.0002	.02	.02	.001	1.0
	13.	.6	.006	.009	<.0001	.01	.001	.001	.02
SG-9, String 2	.2	.18	<.02	.4	--	.02	.009	.004	.1
	1.3	<.05	.02	.1	.0001	.04	.001	<.001	1.0
	1.2	1.3	.01	.6	.0003	.007	ND	<.002	.06
	.7	1.8	<.01	.3	.0001	.01	ND	<.001	.03
	2.4	7.	.01	.3	.00009	.03	.03	<.001	.03
SG-6, String 3	.3	.44	.007	.2	.0029	.02	<.004	.002	.7
	.1	.2	.003	.1	<.0001	.004	<.001	.001	.04
	.2	.1	<.02	.2	<.00003	.009	ND	.001	.02
	2.0	<.1	<.01	.3	.00009	.009	<.01	<.001	.02
SG-11, String 3	4.4	<.05	.01	.02	.0002	.006	.003	<.001	.4
	7.3	<.05	.01	.3	.0002	.005	ND	<.001	.01
	6.	6.	.01	.1	.0001	.01	<.006	<.001	.03
SG-10A	.41	.08	.01	.03	.0001	.01	.007	<.002	.3
	.5	1.1	.01	.06	.0002	.009	.02	.006	.06
	.4	.1	.01	.1	.00012	.01	<.004	<.001	.03
SG-17, String 2	17.	<.05	.02	.01	.0031	.01	.007	.006	2.
	16.	.09	.01	.03	.0009	.006	<.001	<.001	.05
	11.5	<.1	.02	<.1	<.0003	.02	ND	.002	.02
	17.	.1	.008	<.1	.00008	.006	.001	<.001	.02
SG-18A	190.	<.02	<.02	.02	.0024	.005	ND	.001	.03
	.1	<.05	.01	.03	.0003	.01	.004	<.002	.7
	6.3	.8	.004	.03	<.0001	.006	ND	.002	.01
	5.6	<.1	<.02	<.1	.00012	.006	<.006	<.001	.04
SG-19	3.1	<.05	<.008	.002	.0019	.002	ND	<.001	.05
	24.	<.05	.009	.01	.0003	.02	ND	--	2.
	22.	.4	.03	.006	.0002	.009	ND	.002	.05
	23.	<.1	.004	<.1	.00009	.01	<.001	<.001	.01
SG-20	25.	<.05	.008	.007	.0002	.03	.002	<.001	.04
	21.5	.3	.01	.01	.0001	.006	ND	<.001	.04
	22.	<.1	.005	<.1	<.00003	.009	ND	.001	.03
	21.	<.1	<.02	<.1	.00008	.007	<.003	.002	.008
SG-21	8.6	<.05	.01	.03	.0003	.02	.003	.003	.1
	9.3	.2	.007	.03	<.0001	.004	ND	.003	.03
	9.	.2	.02	<.1	.0001	.01	<.006	<.001	.02

Table A-22

MINOR TRACE ELEMENTS - UPPER AQUIFER

WELL	Y	Sr	Rb	Br	Ge	Ga	Ti	Sc	W
Cb-2		.7	.02	.03		.003	.07	<.001	
		.8	.02	.03		<.001	.03	<.002	.01
		2.	.003	.01			.05	<.001	
		.2	.009	.01		.001	.04	<.003	
Cb-4		2.	.006	.03		.003	.08	.002	
		3.	.02	.06		<.002	.3	<.004	.02
		5.	.003	.05		.001	.2	<.001	
		1.7	.02	.003		<.003	.03	<.006	
AT-1^c String 3		2.	.01	.02			.08	.002	
		3.	.04	.02		<.001	.05	<.003	
		3.	.02	.05	<.002	<.002	.2	<.001	
		3.6							
		1.8	.02	.005		<.002	.07	<.004	
SG-1 String 2		2.	.006	.02			.03	.006	
		3.	.008	.02			.3	<.001	
		3.		.006			.2	<.007	
		3.3	.01	.009	<.002	.001	.05	<.003	
SG-6 String 3	<.001	17.	.02	.01			.05	<.003	
			.009	.01			.2		
		7.3	.003	.01			.003	<.005	
		6.	.002	.004		.002	.1	<.004	
SG-8 String 2		3.	.04	.05	.002	.002	.08	<.003	
	.01	1.	.02	.02	<.001	.003	.1	<.001	
SG-9 String 2		3.	.02	.03			.05	.009	.01
		2.	.02	.03		.001	.03	.002	
		4.	.05	.06			2.	<.001	
		2.5	.02	.02			.08	<.003	
		4.	.01	.09		.003	.08	<.005	
SG-10A		4.	.003	.02		<.002	.03	<.005	
		4.	.03	.2			.3	<.002	
		1.7	.02	.02		<.002	.08	.005	
SG-11 String 3		3.	.04	.05		<.001	.05	<.003	.02
			.02	.03			.1	<.001	.002
		1.7	.05	.007		.002	.08	.005	
SG-17 String 2		.2	.03	.2			.3	.005	.02
	<.001	.7	.009	.05	.002		.05	<.001	.003
		.1	.007	.03		.004	.06	<.004	
		.2	.008	.01	<.001	.001	.04	<.001	
SG-18A		.3	.004	.01		--	.04	.003	
		2.	.01	.008			.03	<.002	
		3.	.01	.01			.3	<.001	
		1.9	<.002	.004		<.003	<.1	<.007	
SG-19		.4	.005	.01		.002	.03	.001	
		.4	.006	.008		.001	.1	<.002	.01
		.4	.006	.02	<.002		.05	<.001	
		.4	.004	.006	.001	.001	.02	<.002	
SG-20		.7	.02	.01		<.001	.2	<.003	
		.4	.007	.03		<.001	.02	<.001	
	<.001	.4	.01	.01		.001	.02	<.001	
		.5	.008	.006		.004	.06	<.004	
SG-21		2.	.006	.02		.002	.03	.006	
		.5		.02		<.002	.04	<.001	
		1.	.02	.004		.003	.09	<.006	

Table A-23

MINOR TRACE ELEMENTS - UPPER AQUIFER

WELL	U	Th	Cs	I	Sb	Ag	Mo	Zr
CB-2							.04	
	.03		.007	.003	.01	<.001	.04	.002
			<.001		<.001		.009	
			.003	.001			.03	.001
Cb-4				.004			.02	
	.02		.01	.02	.008		.04	
	<.002		.001	.004				
			<.003	.003			.03	<.003
AT-1c String 3				.002			.02	
	<.001		.004	<.001	.003		.03	
	<.001		.008	.003		<.003	.02	
			.002	.002	.002		.02	.002
SG-1 String 2			.003	.006			.02	<.002
	.002	<.001		<.001			.03	.001
				.005				
			.01	.003		.02	.03	.001
SG-6 String 3			.004	.004			.003	<.001
				<.001		<.002	.01	
								.004
			.002	.002			.04	.003
SG-8 String 2	.007		.04	.02			.01	.003
	.004		.02	.002	<.001	<.001	.01	.001
SG-9 String 2			.005	.005	.006		.08	
			.003	.003	.02		.02	.001
				.01			.05	
			.003				<.01	
			.002	.003			.02	
SG-10A			<.002	<.002			.04	<.002
			.02	.02		.05	.09	
			<.002	.002			<.007	<.002
SG-11 String 3	.002		.01	.02	.006		.01	
	<.001		<.001	.006	.002	.001	.01	
			.03	.002			.02	.002
SG-17 String 2			.2	.08			.1	.03
	<.001	<.001	.02	.004		<.001	.02	.003
			.004	.01			<.02	
			.01	.002		<.002	.006	
SG-18A							.03	--
			<.002	<.002			.01	
				.002			.03	.003
							.03	.01
SG-19			.001	.004			.003	.002
			.01	.001	.001	.001	.008	.009
	<.001	<.001		.006			.01	.03
			.002	.002			.003	.001
SG-20			.01	.002			.03	.01
	<.001	<.001	.003	.003			.006	.006
			.002	.002		.001	<.008	.004
			.005	.004				
SG-21			.002	.003			.02	
			.02	.005		.003		.03
			<.002	.002			.02	

Table A-24

WATER QUALITY PARAMETERS - LOWER AQUIFER

Well	Conductivity	pH	TDS	Alpha Rad.	Beta Rad.	DOC	TOC
Cb-1	3900	8.7	2500	4	0		<1
	4000	8.7	2500	18	0		6
	3800	9.1	2200	8	0		4
	4097	8.7	2570	19	0	*	
AT-1c, String 1	1400	9.0	1200	4	41		<1
	1100	9.0	800	10	0	5	4
	1400	9.0	780	9	0		2
	1300	8.8	792			5.8	
	1415	9.0	817	18	33	*	
AT-1c, String 2	1400	8.5	890	2	0		<1
	1200	8.8	760	7	0	2	2
	1200	9.0	720	10	0		2
	1250	8.8	744			5.0	
	1329	8.7	748	8.5	24	*	
SG-1, String 1	4400	8.7	3000	23	0	4	6
	2900	8.9	1900	13	0		5
	7000	8.4	5236			11	
	8369	8.7	5747	33	0	*	
SG-6, String 1	2100	8.4	1300	4	12	7	6
	2700	9.1	1700	16	0	35	40
	2300	8.8	1542	18	4	9	
	3099	8.8	1894	6.2	33		
SG-6, String 2	1200	8.8	830	6	0		7
	1300	8.9	810	3	0		5
	630	9.3	356	1.3	0	8.4	
	2211	8.9	776	4.4	0	*	
SG-8	1800	8.8	1200	3	0		5
SG-8R	1850	9.0	1197			4	
	1350	8.6	885	4	11	35	
	1889	8.8	1167	6.6	9	*	
SG-9, String 1	1400	8.4	1000	4	0		<1
	3100	8.6	2000	6	0		8
	1400	9.0	880	6	0		4
	1700	8.6	1316			175	
	1378	8.6	1411	8.4	34	*	
SG-10	45000	8.3	42000	320	0	25	26
SG-10R	4900	8.1	2753	0	15	6.6	
	4690	8.2	2550	9.9	6	*	
SG-11, String 1	40000	8.8	39000	43	390		38
	40000	8.4	39000	460	0	26	25
	36000	8.6	39000	36	0	23	25
String 1R	20420	8.6	15870	0	70	*	
SG-11, String 2	1200	8.7	870	8	0	3	2
	1200	9.0	710	7	0		3
	1287	8.7	726	6	16	*	
SG-17, String 1	32000	8.5	28000	3	0	20	18
	29000	8.7	28000	20	0	15	17
String 1R	9600	8.6	6486			58	
	6768	8.7	4300	17	2	*	

*Samples contaminated with acetone

Table A-25

MAJOR CONSTITUENTS - LOWER AQUIFER

	NH_3	HCO_3	Ca	CO_3	Cl	OH	Li
Cb-1	2.1	2500	4	62	64	<.1	<.5
	3.4	2700	5	43	30	<.1	<.5
	1.2	2200	3	83	9	<.1	<.5
	2.2	2670	4	55	17	--	<.5
AT-1c, String 1	0.1	780	4	160	36	<.1	<.5
	1.0	780	4	30	4	<.1	<.5
	0.6	710	5	24	38	<.1	<.5
	3.1	748	4.8	21	4.4	--	--
	.6	738	5	30	9	--	<.5
AT-1c, String 2	0.4	420	28	7	9	<.1	<.5
	0.4	740	7	18	3	<.1	<.5
	0.6	660	6	22	3	<.1	<.5
	2.8	716	6.3	16	1	--	--
	.36	722	6	14	3	--	<.5
SG-1, String 1	4.4	2600	12	62	280	<.1	1.3
	1.7	1800	6	54	68	<.1	<.5
	9.5	3730	6.9	160	610	--	4.1
	15.5	4300	7	120	700	--	5
SG-6, String 1	6.3	820	16	12	180	<.1	<.5
	3.7	1400	2	60	131	<.1	<.5
	5.2	1430	5.4	35	19	--	<.5
	2.2	1860	7	47	50	--	<.5
SG-6, String 2	1.8	600	8	18	73	<.1	<.5
	2.5	700	8	42	48	<.1	<.5
	3.0	265	4.7	17	31	--	<.5
	.76	744	5	20	12	--	<.5
SG-8	1.8	1200	3	30	3	<.1	<.5
SG-8R	1.1	1196	5	36	10	--	<.5
	.3	880	2.8	17	4.4	--	<.5
	.95	1150	4	32	7	--	<.5
SG-9, String 1	0.1	970	19	17	28	<.1	<.5
	6.8	1700	4	26	138	<.1	1.5
	0.9	870	5	24	11	<.1	<.5
	3.1	1200	4	20	80	--	.8
	3.45	1290	5	24	98	--	.9
SG-10	197.	25000	5	1600	9800	<.1	79
SG-10R	.6	104	216	--	1370	--	.5
	3.8	287	127	--	1263	--	<.5
SG-11, String 1	--	22000	6	2000	8150	<.1	79
	91.	21000	16	1700	9800	<.1	63
	130.	23000	6	1500	8200	<.1	76
String 1R	25.5	11300	9	288	3280	--	23
SG-11, String 2	0.5	740	10	21	20	<.1	<.5
	1.2	630	10	21	9	<.1	<.5
	1.15	677	7	15	8	--	<.5
SG-17, String 1	100.	18000	11	720	6900	<.1	43
	150.	17000	9	1000	6200	<.1	58
String 1R	16.8	4740	8.9	130	1064	--	5
	12.0	3260	10	108	640	--	2.6

Table A-26

MAJOR CONSTITUENTS - LOWER AQUIFER

	Mg	NO_3	PO_4	K	Na	SiO_2	SO_4
Cb-1	4	0.5	<.1	9	1100	12	<4
	4	0.9	<.1	14	1100	15	12
	3	2.9	<.1	4	1000	13	<4
	3	.02	.04	5	1120	17	10
AT-1c, String 1	4	<.1	<.1	--	520	12	96
	4	<.1	<.1	7	320	10	17
	3	0.2	<.1	8	330	6	<4
	3.6	.1	.08	6.6	327	11	25
	3	.08	.03	10	340	12	17
AT-1c, String 2	29	1.0	<.1	6	230	16	350
	8	<.1	<.1	3	310	19	14
	6	0.2	<.1	3	290	13	33
	5	<.04	.02	4.2	304	13	25
	4	.22	.03	2	310	14	22
SG-1, String 1	15	<.1	<.1	12	1200	13	150
	8	1.8	<.1	5	780	11	<4
	11.6	.10	.02	20	2130	11	316
	10	.28	.02	20	2320	17	313
SG-6, String 1	9	1.6	<.1	32	450	5	180
	3	3.4	<.1	13	770	3	16
	3.4	.96	.07	7.3	660	9	82
	4	.24	.07	6	800	15	26
SG-6, String 2	16	<.1	<.1	11	290	2	110
	7	2.9	<.1	5	330	4	<4
	1.9	<.04	.04	2.5	143	2	16
	4	.16	<.02	2	320	11	17
SG-8	3	0.2	<.1	1	490	13	24
SG-8R	3	.04	.06	1.8	505	5	29
	1.5	<.04	.24	3.1	358	21	25
	3	<.02	.07	2	515	14	<4
SG-9, String 1	8	<.1	<.1	5	410	13	67
	4	<.1	<.1	7	830	12	57
	3	0.2	<.1	2	370	14	<4
	2.9	.12	<.02	3.7	548	13	12
	3	.24	.02	4	575	17	12
SG-10	10	0.5	0.7	122	17000	21	25
SG-10R	111	.2	.05	11.3	640	2	329
	110	<.02	.01	10	650	11	211
SG-11, String 1	14	<.1	<.1	125	16000	24	2
	10	0.6	<.1	120	16000	38	90
	4	0.3	<.1	122	16000	21	<4
String 1R	8	.06	.24	34	6140	19	20
SG-11, String 2	13	<.1	<.1	5	330	10	82
	10	<.1	<.1	2	280	13	38
	6	.34	<.02	3	295	11	29
SG-17, String 1	13	0.5	<.1	85	11000	24	120
	7	0.2	<.1	91	11000	20	<4
String 1R	7.1	.12	<.02	18.6	2680	17	41
	7	<.02	.04	11	1800	17	7

Table A-27

IMPORTANT TRACE ELEMENTS - LOWER AQUIFER

	Al	As	Ba	Be	B	Cd	Cr	Co	Cu
Cb-1	.05	.002	.08	ND	.7	ND	.006	.01	.09
	.08	.008	.3	ND	.9	ND	<.01	.01	.03
	1.0	.002	.2	<.001	.8	ND	<.01	<.001	.02
	.6	.004	.4	.001	1.	.01	.004	.004	.03
AT-1c, String 1	.9	.03	.04	<.001	1.1	ND	.003	.006	.1
	.08	.003	.3	ND	.43	ND	<.01	.004	.03
	.05	.005	.04	ND	.6	ND	<.01	<.001	.02
		.003							
	1.	.020	.1	ND	.05	ND	.01	<.009	.2
AT-1c, String 2	.5	.05	.1	.002	1.4	ND	.005	.003	.03
	.4	.01	.2	ND	.64	ND	<.01	.001	.02
	.1	.02	.2	ND	.8	ND	<.01	ND	.007
		.03							
	.04	.007	.1	ND	.1	ND	.009	<.007	.004
SG-1, String 1	--	.005	.09	<.001	12	ND	<.01	<.001	.09
	.5	.004	.1	ND	.7	ND	<.01	<.001	.03
	.09	.03	.04	ND	10	ND	.003	<.006	.09
	.06	.06	.02	ND	--	ND	.002	<.01	.02
SG-6, String 1	.5	.003	.06	ND	.65	ND	<.01	<.001	.03
	.09	.01	.02	ND	.2	ND	<.01	<.001	.005
	.005	.003	.1	ND	.2	ND	.003	<.001	.01
	.1	.009	.2	.001	.7	ND	.005	<.002	.04
SG-6, String 2	--	.009	.06	ND	.70	ND	<.01	<.001	.01
	.1	<.002	.03	ND	.4	ND	<.01	<.001	.003
	.02	.002	.07	ND	.1	ND	.01	<.005	.03
	.03	.001	.02	ND	.3	ND	.007	.006	.01
SG-8	.01	.02	.4	ND	1.1	ND	<.01	ND	.02
SG-8R	.09	.006	.1	<.001	.08	ND	.007	<.002	.03
	2	.03	.4	ND	.05	ND	.01	<.001	
	.3	.030	.5	<.001	.05	ND	.009	<.004	.01
SG-9, String 1	.4	.02	.08	.001	4.9	.1	.006	.002	.03
	.05	.006	.08	ND	4.3	ND	<.01	.002	.009
	.2	.005	.1	ND	1.4	ND	<.01	ND	.004
	.1	.016	.08	ND	.3	ND	.02	<.009	.02
	.07	.020	.2	<.001	.8	ND	.007	.003	.02
SG-10	.3	--	5	<.001	405	ND	<.01	ND	.9
SG-10R	.03	.006	.09	ND	.6	<.01	.01	.003	.04
	.03	.010	.09	<.001	.6	ND	.02	.02	.02
SG-11, String 1	0.4	.03	5	.002	315	ND	.007	.03	0.2
	0.04	.2	2	ND	305	ND	<.01	<.009	.2
	.08	.1	2	<.001	310	<.007	<.01	.02	.02
String 1R	.04	.040	6	.001	--	ND	.007	<.02	.1
SG-11, String 2	.08	.05	.09	ND	1.1	ND	<.01	<.001	.01
	.4	.06	.09	ND	2.7	ND	<.01	<.001	.004
	.07	.006	.1	ND	.3	ND	.02	<.01	.009
SG-17, String 1	.2	.09	8	.001		ND	<.01	<.02	.04
	.3	.04	3	.001	200	ND	<.01	<.008	.2
String 1R	.002	.009	.3	ND	7	ND	.003	<.002	.008
	.09	.020	.7	<.001	9	ND	.005	.002	.03

Table A-28

IMPORTANT TRACE ELEMENTS - LOWER AQUIFER

	F	Fe	Pb	Mn	Hg	Ni	Se	V	Zn
Cb-1	16	.3	<.008	.2	--	.009	ND	.002	.04
	28	<.05	.02	.002	.0001	.06	.004	.004	.09
	23	.4	.02	.1	<.0001	.008	ND	.001	.03
	28	<.1	.008	<.1	.00007	--	<.002	<.001	.01
AT-1c, String 1	10	.2	.02	.06	.0019	.02	ND	.003	.2
	19	<.05	.01	.04	.0001	<.001	.002	<.001	.7
	17	<.05	.02	.02	<.0001	.01	ND	<.001	.005
	18	.3		<.1					
	20	6	.1	.1	.00004	.02	<.004	.001	.04
AT-1c, String 2	9	.18	.03	.2	.0009	.006	ND	.002	.05
	16	<.05	.02	.3	.0004	<.001	.003	.001	.05
	17	<.05	.008	.1	<.0001	.004	ND	<.001	.02
	15.5	.1		<.1					
	17	.1	<.01	<.1	.00007	.003	<.002	<.001	.01
SG-1, String 1	21	<.05	.02	.1	.0003	.02	--	<.001	.1
	20	.1	.01	.1	.0001	.004	ND	<.001	.2
	28	<.1	<.01	.1	.00003	--	ND	<.006	.03
	25	<.1	<.03	.1	.00009	--	<.008	<.006	.009
SG-6, String 1	11	<.05	.01	.2	.0027	.02	ND	.002	.03
	20	.2	.006	.03	<.0001	.005	ND	.002	.06
	16.4	<.1	<.005	.1	<.00003	.005	ND	.001	.01
	22	<.1	<.004	.1	.00008	--	<.001	.001	.02
SG-6, String 2	12	<.05	.01	.02	.0016	.006	ND	<.001	--
	15	<.05	.003	.06	<.0001	.008	.001	<.001	.2
	6.5	.1	<.02	<.1	<.00003	.007	ND	.002	.05
	17	.1	.01	<.1	.00015	.01	<.004	<.001	
SG-8	26	<.05	.009	.05	.0001	.006	--	.001	.5
SG-8R	14	.3	.05	<.1		.01	<.001	<.001	.03
	16.6	1.2	<.01	<.1	<.00003	.01	ND	.001	.02
	23	<.1	<.008	<.1	.00006	.01	<.002	<.001	.02
SG-9, String 1	18	.68	.01	.09	--	.003	.005	.002	1
	25	<.05	.01	--	.0002	--	ND	.004	.05
	19	.9	<.004	.03	<.001	.004	ND	<.001	.01
	21	<.1	<.01	.1	<.00003	.02	ND	.003	.07
	20	.2	<.006	<.1	.00011	--	.002	<.003	.02
SG-10	47	3.1	.04	.1	.0001	--	--	.1	.03
SG-10R	4.4	<.1	.004	.2	.0002	--	<.003	.002	.02
	4.	2.4	<.01	.6	.00006	--	<.003	.001	.09
SG-11, String 1	48	2.3	.03	.07	.0026	--	ND	.02	.03
	46	<.05	.4	.04	.0002	--	.01	.1	.05
	42	7.7	.04	.04	.002	--	.006	<.05	.01
String 1R	26	1.8	<.03	.1	.00023	---	ND	.03	.03
SG-11, String 2	14	<.05	.04	.05	.0003	.04	.004	.002	4
	14	.8	.004	.05	.0001	.006	ND	.002	.06
	17	.1	.03	<.1	.0001	.02	ND	.001	.01
SG-17, String 1	34	1.5	.07	.09	.0001	--	.02	.03	.05
	37	7.9	.07	.1	.0001	--	.006	<.04	.02
String 1R	21	<.1	.005	.1	<.0001	--	<.002	.007	.005
	21	<.1	.02	.1	.00009	--	<.003	<.001	.005

Table A-29

MINOR TRACE ELEMENTS - LOWER AQUIFER

	Y	Sr	Rb	Br	Ge	Ga	Ti	Sc	W
Cb-1		.4	.01	.03			.05	<.001	
		.6	.04	.01		.003	.2	<.003	
	<.002	.2	.01	.03	<.001	<.001	.01	<.001	
	<.001	.4	.02	.01	<.002	.001	.05	<.003	
AT-1c String 1		.4	.1	.05		.002	.08	.002	
	<.001	1	.04	.01	.002	<.001	.08	<.001	.02
		0.5	.01	.01	<.001		.01	<.001	.004
		.7							
		.3	.04	.01		<.003	.01	<.007	
AT-1c String 2		5.	.05	.03			.1	.003	
	<.001	1.	.02	.008		<.001	.03	.002	.05
		2.	.009	.01			.09	<.001	
		.9							
		.6	.007	.004		<.003	.03	<.001	
SG-1 String 1		.9	.1	.2		.002	.006	.002	.01
		1	.006	.05			.05	<.001	
		.4	.03	.3		.002	.2	<.002	
	<.02	.2	.01	.08	<.02	.01	.08	<.01	<.02
SG-6 String 1	.01	.7	.09	.05		.001	.05	.006	
		.1	.05	.1	<.003	<.001	.02	<.001	.008
		.2	.01	.009			.01	<.001	
		.2	.009	.01	<.001	.001	1.	<.004	
SG-6 String 2		.7	.04	.05		<.001	.05	.003	
		.6	.02	.05			.04	<.001	
		.3	.04	.03		<.003	.04	<.002	
		.3	.005	.003		.002	.03	<.005	
SG-8	<.001	.8	.006			.002	.01	.002	.01
SG-8R	<.001	.4	.04	.006		.001	.4	<.001	<.002
		.3	.01	.02			.3	<.004	
		.6	.01	.006	<.002	.002	.02	<.003	
SG-9 String 1		2.	.05	.03		.003	.1	.002	.01
		.2	.01	.2		.002	.3	.002	.008
		.3	.01	.03	<.001		.01	<.001	
	.001	.4	.03	.05		.003	.04	<.003	
		.2	.006	.03		.001	.04	<.002	
SG-10	<.02	2.	.4	10	.05	<.03	.03	.01	
SG-10R	<.001	10.3	.05	.1		<.001	.3	<.002	
	<.001	8.7	.04	.07	.02	.007	.2	<.004	
SG-11 String 1	.03	3.	.04	.8	.05	.02	.2	.01	
	<.01	1.	.9	8		<.03	.3	<.007	.02
	<.008	.8	.04		<.007	<.01	.2	<.004	
String 1R	<.03	1.2	.2	.6		<.007	.1	.01	
SG-11 String 2	.01	2.	.05	.03			.03	.004	.009
		1.	.02	.01		<.001	.06	<.002	
		.4	.05	.006		.005	<.08	<.006	
SG-17 String 1	<.03	6.	.4	3.	.02	<.06	1.	<.008	.04
	<.003	2.	.3	7.	<.04	<.03	.1	<.01	
String 1R		.4	.02	.3		<.001	.03	<.002	
		.6	.01	.3		<.004	.2	<.008	

Table A-30

MINOR TRACE ELEMENTS - LOWER AQUIFER

	U	Th	Cs	I	Sb	Ag	Mo	Zr
Cb-1			.002	.002			.02	
			.009	.004				.004
			.02	.008			.02	.003
			.01	.002			.005	.002
AT-1c String 1			.07	.006	.03		.07	.004
	.002		.04		.006		.03	<.001
	<.001		.003	.003	<.001			
			.01	.002	.04		<.008	.003
AT-1c String 2			.02	.01			.1	
			.03	.003	.002		.08	.01
			.002	<.001		<.002	.02	
			.008	.002			.008	.002
SG-1 String 1	.02		.1	.06	.007		.1	.08
			.02	.01			.02	<.001
			.07	.06	<.01			.009
			.01	.06	<.01		<.02	.01
SG-6 String 1			.01	.02			.01	
	<.001	<.001	<.001	.04	.006		.1	.002
			<.001	.002	.004		.01	
			.003	.001			.02	<.001
SG-6 String 2	.02		.02	.02	.002		.1	
				.004		<.002	.06	
			.005	.01	<.004		.03	<.003
			.005	.002			.02	.002
SG-8	.001		.01	.003			.008	.002
SG-8R	.003		.04	.001	<.001	<.001	.03	.001
			.001	<.001			<.008	<.002
			<.002	.001			<.004	.007
SG-9 String 1			.01	.01	.009	.009	.07	
			.05	.1	.01		.04	.005
			.005	.003			.02	<.001
			.02	.008			.03	.004
			<.003	.003	<.001		.02	.006
SG-10	.008		3	2		.02	.08	.4
SG-10R			.02	.002	<.02		<.007	.001
			.03	.005	.01	<.01	.008	.002
SG-11 String 1			.04	.5	.008		.01	.9
	.006		4	3	.08		.1	.6
			.1	2.		.02	.03	.2
String 1R			.04	.08	< .01	<.01		.1
SG-11 String 2			.01	.02	.004		.2	
			.01	.006			.08	
			.04				<.05	.009
SG-17 String 1			2.	2.			.04	.3
	<.003		1.	2.	.04	<.01	.02	.3
String 1R			.07	.2	.002		.02	.008
			.005	.05				.003

Table A-31

RADIOACTIVE ELEMENT ANALYSES

Date	Source	Ra^{226}, pCi/l	U, mg/l
10-76	A-1	0.0 ± 0.5	0.003
10-76	A-2	0.0 ± 0.4	<0.002
10-76	A-3	0.0 ± 0.5	0.002
10-76	A-5	0.0 ± 0.4	0.004
10-76	A-6	0.3 ± 1.0	0.003
5-76	A-7	0.0 ± 0.4	0.0063
10-76	A-7	0.0 ± 0.5	0.005
6-76	A-8	0.1 ± 0.5	0.002
10-76	A-8	0.2 ± 0.6	0.003
10-76	A-10	0.0 ± 0.4	0.003
10-76	A-11	0.0 ± 0.5	0.003
5-76	A-11	0.0 ± 0.4	0.002
10-76	A-12	0.0 ± 0.5	0.003
5-76	S-1	0.0 ± 0.4	<0.0015
10-76	S-1	0.7 ± 0.6	<0.002
5-76	S-2	0.0 ± 0.4	<0.0015
10-76	S-2	0.9 ± 1.5	0.003
5-76	S-3	0.0 ± 0.3	<0.0015
10-76	S-3	0.0 ± 0.5	0.003
5-76	S-4	0.1 ± 0.4	<0.0015
5-76	S-6	0.1 ± 0.4	<0.0015
10-76	S-6	0.0 ± 0.6	0.003
10-76	S-7	0.0 ± 0.5	0.003
10-76	S-8	0.0 ± 0.6	0.002
10-76	S-9	0.0 ± 0.5	0.002
5-76	S-10	0.0 ± 0.3	<0.0015
10-76	S-10	0.1 ± 0.6	0.002
10-76	Cb-1	0.2 ± 0.7	<0.002
10-76	Cb-2	0.0 ± 0.6	<0.002
10-76	SG-1, Str. 1	0.0 ± 0.5	0.013
5-76	SG-6, Str. 1	0.0 ± 0.3	<0.0015
5-76	SG-6, Str. 3	0.0 ± 0.4	<0.0015
10-76	SG-6, Str. 1	0.0 ± 0.7	<0.002
10-76	SG-6, Str. 2	0.0 ± 0.5	<0.002
10-76	SG-6, Str. 3	0.0 ± 0.5	<0.002
10-76	SG-8	0.0 ± 0.6	<0.002
10-76	SG-9, Str. 1	0.2 ± 0.8	<0.002
10-76	SG-10	0.1 ± 0.5	<0.002
10-76	SG-10A	0.0 ± 0.5	<0.002
10-76	SG-11, Str. 2	0.0 ± 0.7	<0.002
10-76	SG-11, Str. 3	0.0 ± 0.6	<0.002
10-76	SG-17, Str. 1	1.5 ± 0.8	<0.002
10-76	SG-18A	0.0 ± 0.8	<0.002
10-76	AT-1c, Str. 1	1.0 ± 1.4	0.003
10-76	AT-1c, Str. 2	0.2 ± 0.6	<0.002
10-76	AT-1c, Str. 3	0.5 ± 0.7	<0.002
2-76	Snow, Cb-2	0.0 ± 0.4	